Mechanical Site Preparation and Forest Regeneration in Sweden and Finland: Implications for Technology Transfer

by
J. A. Hunt[1]
and
R. G. McMinn[2]

[1] #3-1268 McKenzie Street
Victoria, B.C. V8V 2W5

[2] Millstream Lake Road
R.R.#6, Victoria, B.C.
V8X 3X2

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Canadian Forestry Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5
(604) 388-0600

or

B.C. Ministry of Forests and Lands
Research Branch
31 Bastion Square
Victoria, B.C. V8W 3E7
(604) 387-6719

ABSTRACT

Sweden and Finland have a relatively long history of intensive reforestation practice. Forest legislation ensures compliance with established procedures. Given the similarity of boreal forests in Canada, Sweden and Finland, forest managers in British Columbia should be able to capitalize on Fennoscandian technology to reduce the time and cost of developing silvicultural methods. The site-specific nature of site preparation and reforestation, nevertheless, affects the transferability of technology. Methods and machinery may require modification for local application. Site preparation equipment that can provide a range of micro-sites, including elevated planting spots, is increasingly favoured in Fennoscandia. The need for increased biological knowledge and the necessity of training field staff and machine operators before "site-adapted" reforestation can become a reality is also recognized. Technology exchange between Canada and Fennoscandia can provide British Columbia with an opportunity to gain experience in site-specific mechanized silviculture, at reduced costs.

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This report was initiated in response to interest expressed by the International Branch of the Canadian Forestry Service in a project to assess forest regeneration practice in Sweden and Finland (Fennoscandia). Trends, prospects, and the applicability of Fennoscandian techniques to Canada were examined. Major emphasis was on mechanical site preparation.

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1 INTRODUCTION

Swedish and Finnish (Fennoscandian) mechanical site preparation[1] experience is extensive. An understanding of its evolution should benefit development of site preparation in Canada. Since site preparation is just one component of forest regeneration, which in turn is integrally related to the whole process of forest management, a technical study of site preparation was thought to be insufficient without some discussion of silviculture in Fennoscandia. This report, therefore, describes some trends in Fennoscandian silviculture, and mechanical site preparation and reforestation techniques. Implications for the transfer of this technology to British Columbia are also discussed.

The report is based mainly on visits with researchers, manufacturers and forest companies throughout Sweden and Finland. Literature references were drawn from the senior author's Master of Science studies at the Swedish University of Agricultural Sciences, Department of Silviculture, Umeå, Sweden. Hence, the report contains a preponderance of Swedish references. Regrettably, the language was a barrier to searching Finnish material.

Time constraints limited the scope of the report. Not all current mechanical site preparation techniques used in Fennoscandia are described. Also, the biological aspects of site preparation are not presented in detail because a more comprehensive literature review and discussion than time allowed would have been necessary.

The report includes: some background to aspects of forest management in Fennoscandia that influence silvicultural practice and technology transfer; a synopsis of past and future directions in site preparation and reforestation; guidelines and considerations affecting forest regeneration; a description of the main implements considered to be appropriate for use in Canada; some implications for British Columbia; and appendices summarizing technical information.

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[1] "Mechanical site preparation" is used as a generic term to cover all forms of mechanical site treatment ("cultivation") including plowing, mounding, and disc trenching. Scarification is confined to patch scarification rather than the broader North American usage which may include any form of soil disturbance to promote regeneration.

2 FACTORS AFFECTING TECHNOLOGY TRANSFER

Fennoscandian forestry practices have evolved over a long period of time and have been intensive compared to Canadian activity. Ecological similarities between Canadian and northern European forests suggest that technology (i.e., knowledge and equipment) could be transferred, thus saving time and resources in developing methods. However, how much of this technology is transferable? The site-specific nature of reforestation demands solutions that are adapted to local conditions. Environmental and management constraints differ sufficiently to limit the direct transferability of technology. Therefore, an understanding of the background that influences forest management in Fennoscandia is important for technology transfer.

Europe has long recognized the need for sustained yield forestry. Measures taken to protect Sweden's forest capital and improve yield date back 700 years. A Finnish doctoral thesis in forest management written in 1753 shows how long there has been interest in Finland's forests. However, wood shortages from exploitation have occurred. The historical development of forest practices and extensive background in reforestation research have affected the present methods.

Finland and Sweden annually reforest close to 1% of their productive forest land. The corresponding proportion for Canada would approach 2 million ha. The productive forest area of Canada is about 11 times that of Sweden. Although Sweden annually harvests about one third of the volume harvested in Canada, the area reforested is half that reforested in Canada and more hectares are mechanically site prepared. Comparative forestry statistics for Finland, Sweden and Canada are presented in Table 1.

Sweden and Finland mechanically site prepare 85 and 63% of their respective final harvest areas annually. The corresponding figure for Canada is 19% (Table 1). Mechanization of site preparation implements in Fennoscandia dates from the early 1950's. Well over 200 Swedish and Finnish implements have been exported to Canada and the number is increasing annually.

TABLE 1. Some annual forest statistics for Finland, Sweden, and Canada[a]

	Finland[b]	Sweden[c]	Canada[d]
Total land area (km²)	305 470	450 000[e]	9 170 000
Total forest area (x 1000 ha)	26 778	30 795	342 500
Productive forest area (x 1000 ha)	20 065	23 615	220 200
Growing stock (million m³)	1 660	2 573	19 644
Increment (million m³)	68.36	84.33	338.0[f]
Current annual growth (m³/ha per year)	3.4	3.6	1.7[f]
Total volume cut (million m³)	41.5	55.9	156.9
Area final harvested[g] (x 1000 ha)	178.5	209.5	776.6
Artificial regeneration area (x 1000 ha)	140.5	180.8	242.6[h]
% Harvested area naturally regenerated	26.3	25.0[i]	N/A
Site preparation (x 1000 ha)			
Mechanical	112.9	178.0	150.1[h]
Burning	1.8	negligible	37.4[h]
Other			32.7[h]
Area planted (x 1000 ha)	114.5	j	192.3[h]
Area seeded (x 1000 ha)	26.0	negligible	50.3[h]
No. seedlings planted (x million)	221.4	500.0[k]	N/A
No. supplementary planted (x million)	20.5	43.9	N/A

[a] Discrepancies due to differences in year of inventory.
[b] Anon. (1986a)
[c] Swedish National Board of Forestry (1986)
[d] Canadian Forestry Service (1986)
[e] Swedish Institute (1985)
[f] Honer and Bickerstaff (1985)
[g] Includes seed tree/shelterwood area.
[h] Kuhnke and Brace (1986)
[i] Anon (1986b)
[j] Would correspond to the above artificial regeneration area which is overestimated by about 10%.
[k] Örlander (1985)
N/A Not available.

2.1 Biological Constraints

The forests of Fennoscandia within the boreal zone have a similar ecology to that of Canadian boreal zone forests. In Europe, the Gulf Stream moderates the effects of more northerly latitudes. Effective aggregate temperatures are comparable to Canadian boreal conditions, though there is considerable climatic range as temperature sums double from north to south (Figure 1).

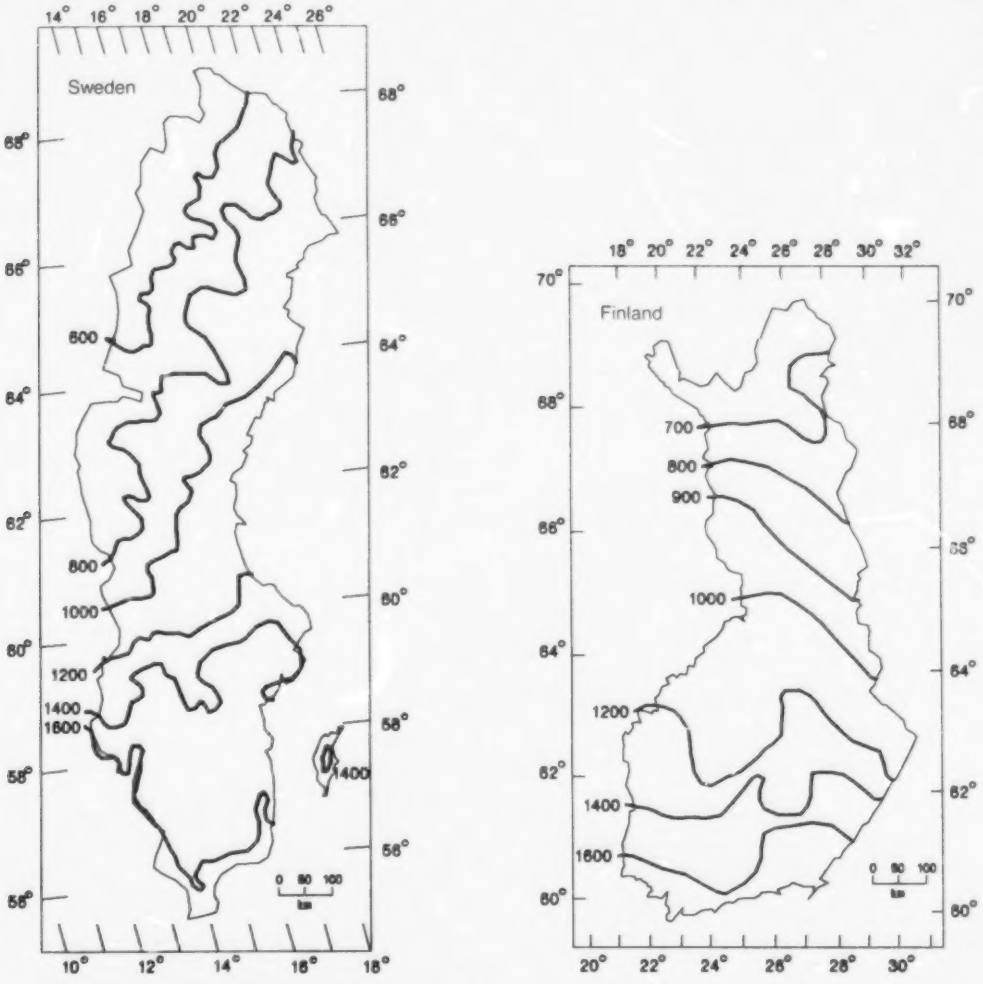

FIGURE 1. Aggregate temperature sums (above 5°C threshold) for Sweden and Finland. Adapted from Odin *et al.* (1983) and Mälkönen (1986).

Variation in soil texture is less in Fennoscandia than in Canada. Fennoscandian soils are relatively stony and shallow with a fairly low proportion of fine texture classes. Soils commonly are more uniform over larger areas than in many Canadian boreal forests.

Silvicultural strategies are affected by the age class distribution of the forest. Swedish forests are currently characterized by an over-representation of mature and young stands and a shortage of middle-aged stands. This "timber depression" provided an impetus for intensive silviculture. It is hoped that a decline in timber available for harvest can be avoided through accelerated growth of young stands by optimal silvicultural measures. Minimizing regeneration delays by appropriate site preparation is also an important consideration.

2.2 Social/Political Constraints

In Fennoscandia, forest laws have been enacted to bring about a high level of forest management. Stocking requirements are relatively high (see Section 3). In both Sweden and Finland, private forest owners may obtain subsidies for operations such as road building or regeneration.

Forest management in Sweden is closely controlled by legislation, which requires that:

- cut-over areas be regenerated;
- every management area have a management plan;
- cleaning and thinning to promote forest growth be carried out;
- the forest not have a final harvest before a specified age and the final harvest accommodate the establishment of a new stand;
- low density, damaged or low productivity stands be harvested and a new forest established; and
- insect attacks be prevented and contained.

The Swedish National Board of Forestry is responsible for enforcing this legislation. For example, a landowner who fails to meet the requirements to thin once a specified basal area has been exceeded is first warned; if he still does not comply, he may be fined. Ultimately, the work will be done by the National Board of Forestry at the owner's expense. This rarely happens because the level of compliance with the forest laws is high.

In Finland, legislation enacted in 1967 governing private land requires that "the forest shall not be devastated." Devastation is considered to be any forest operation that leaves an area in such a condition that natural or artificial regeneration is endangered. A minimum volume of growing stock must be left following thinning or forest product removal (Appelroth 1984).

The predominant form of land tenure in Sweden and Finland is private ownership (81 and 68%, respectively). In Canada, provincial and federal ownership amounts to 92% of the forest land base (Table 2). Although the increasing use in Canada of management agreements with large companies reduces the significance of this difference in ownership, the impetus for private owners to provide intensive management and to develop and use innovative silvicultural equipment, has been greater in Fennoscandia than in Canada.

TABLE 2. Forest land ownership in Finland, Sweden, and Canada

	Finland[a]	Sweden[b]	Canada[c]
State	32.3	18.7	92
Private	55.8	49.9	8
Company	7.6	23.8	
Other	4.2	7.6	

[a] Anon. (1986a)
[b] Swedish National Board of Forestry (1986)
[c] Canadian Forestry Service (1986)

The greatest difference in ownership pattern between Fennoscandia and Canada lies in the number of small holdings. There are 311,390 private forest holdings in Finland with a median size of 35 ha (Finnish Ministry of Agriculture and Forestry 1985). In Sweden, there are 240,000 private forest holdings, some 30% of which are less than 50 ha (Swedish National Board of Forestry 1986). Small-scale holdings can affect the economics of silviculture treatments, since costs may increase with smaller areas and greater transport distances. Some large Swedish and Finnish companies that own processing plants may have only half their wood supply originating from their own land. Hence, there is strong motivation to increase production through intensive silviculture, to reduce long-term reliance on outside sources.

Fennoscandian social/political systems provide very comprehensive worker benefits. Labour relations and worker motivation are consequently better than in Canada. The motivation of operators is a very important factor affecting the quality of silvicultural treatments.

Public pressure resulting from increased environmental awareness has also affected reforestation methods. Environmental concerns have virtually ended herbicide spraying, though there are no legal limitations in Finland and, in Sweden, municipal permission must be granted for ground application of herbicides. Harsh site preparation methods have been criticized and the proportion of plowed areas has decreased over the last few years. Swedish silviculture law states that plowing may only be used where other methods are likely to yield unsatisfactory regeneration results (SKSFS 1986). Disc trenching has also been criticized as being excessive soil disturbance. The Finnish National Board of Forestry is currently revising its operating guidelines to include a greater diversity of site preparation methods. Prescribed burning is gaining popularity in Finland because of its "natural" character (Mälkönen 1986).

2.3 Economic Constraints

The value of the forest resources is greater in Fennoscandia than in Canada. Hence there are more funds available for relatively expensive treatments. In Finland, for example, the economics of forest operations results in greater annual stumpage revenues generated from 20 million ha than from 220 million ha in Canada. In Finland, more than 15% of these revenues are returned to the forest to cover silvicultural costs[2].

Retreatments are very expensive and research indicates that supplementary planting contributes little to a stand's production (Braathe 1980; Gemmel 1987). Therefore, satisfactory results must be obtained with the first treatment. If the expense of supplementary planting can be avoided, more resources would be available for more intensive establishment treatments. Some agencies are now paying higher contract prices for better quality "adapted" site preparation.

2.4 Technical Constraints

Despite the stonier soils, it may be technically easier to carry out mechanical site preparation in Fennoscandia than in Canada. The most critical component is slash. Utilization standards in Sweden and Finland are high: managed and thinned stands have the potentially unmerchantable material removed before harvest. Canadian slash loadings may be equivalent to final harvest volumes (e.g., 100 m^3/ha) in northern Finland and Sweden. This difference in slash loading is probably the most serious constraint on the Canadian application of Fennoscandian site preparation technology.

Canada's lack of qualified machine operators is also a constraint. In Fennoscandia, the level of operator training is high, and may be comparable to that of aircraft mechanics (S.-E. Appelroth, pers. comm., Finnish Forest Research Institute). As well, Sweden and Finland have a well developed infrastructure that supports the mechanization of forestry equipment. Servicing of machines is facilitated by relatively short distances within Fennoscandia and direct communication with factories.

Another factor is the rate of travel during site preparation, which may be 2 to 5 times faster in Canada than in Fennoscandia. The slower speeds and lower rates of productivity may give better quality site preparation and less wear on machines. The Swedish and Finnish rates of travel are affected by the relatively stony and shallow soils.

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[2] Appelroth, S.-E. 1986. Basics of forest management in Finland. Finnish Forest Research Institute. Unpublished report.

3 REGENERATION REGIMES IN SWEDEN AND FINLAND

3.1 Regeneration Method: Artificial vs. Natural Regeneration

Organizations may choose between natural and artificial regeneration according to their objectives and the sites on which they are operating.

Artificial regeneration is the preferred method for increasing production. Volume production can be increased 15-20% through the use of genetically improved seed (Samuelsson 1980). More wood can be cut on a sustained yield basis since, with decreased delay between harvest and establishment, the rotation period is reduced.

Nevertheless, small scale private forest owners often prefer natural regeneration because of the cost of planting and unpleasant aesthetics of clearcutting. Natural regeneration (usually seed tree or shelterwood) provides shading that reduces frost risk, high irradiation, snowloading, competing vegetation and, hence, rodent problems. Seed trees can also have favorable effects on ground water levels. However, natural regeneration has some drawbacks too. Performing a number of cuts can be expensive because of seed tree salvage and windthrow; germination is uneven and good seed years are irregular.

Notwithstanding its attractiveness, natural regeneration is often less successful than artificial regeneration. Results from a 1984-85 national survey by the Swedish National Board of Forestry indicated that the minimum requirements of the silvicultural law were met on 73% of artificially regenerated areas, but on only 54% of naturally regenerated areas (Anon. 1986b). Recommendations for improving regeneration results include better adaptation of site preparation to varying site conditions (Anon. 1986b).

Timber quality is greatly influenced by method of stand establishment (Vuokila 1982). Silviculture practices that give fast early diameter growth will result in a soft juvenile core, a greater number of thick branches, and poor technical quality (Persson 1985). Therefore, natural regeneration may be preferred for the production of saw timber, whereas artificial regeneration with low stocking densities and fast initial growth may be preferred for pulp production.

Site has a significant influence on the choice of regeneration system. The Finnish National Board of Forestry has general recommendations for regeneration method according to site. For example, it recommends clearcutting and utilization of advance regeneration for stands in the *Vaccinium* Type on fine-textured soils if sufficient seedlings are present. In their absence, the Board recommends the seed tree method. Clearcutting and planting are only recommended if neither natural regeneration option is available. For stands of the *Myrtillus* Type or in the *Vaccinium* Type on morainal soils, clearcutting and planting are recommended, except on thin humus or rocky sites where seed trees or advance regeneration may be used. On wet mineral soil, clearcutting and plowing followed by planting are recommended (Table 3).

3.2 Stocking Density

Although the recommended number of seedlings per hectare (Table 3, 4) can be varied, it is generally higher in Fennoscandia than in British Columbia.

In Sweden, recommended numbers vary with site index (Table 4). They may also be varied for "difficult to regenerate" areas, such that sites with harsh climates at high elevations in northern Sweden have lower stocking requirements.

Low stocking density decreases the productivity of Norway spruce stands (Braastad 1983; Agestam and Ekö 1985; Elfving 1985). Trees, however, may be more windfirm and rotations may be shortened by low density. At densities of less than 2000 per hectare, production is reduced if distribution is uneven (Fryck 1984). Rectangular rather than square planting patterns have the potential of reducing site preparation and cleaning costs (Lindman *et al.* 1985), but might also reduce wood quality by uneven crowns affecting stem growth patterns.

In Finland, supplementary (fill-in) planting is carried out when stocking levels are between 40 and 70%. Retreatment is necessary if there is less than 40% success; reforestation is considered successful if 70% of the target level is reached.

Regeneration surveys are commonly carried out 2 years after planting or 5 years after natural regeneration. Supplementary planting is usually done in the 3rd year, though some companies do it before because delays reduce production. Swedish legislation stipulates the minimum number of established seedlings allowed at the latest timepoint for supplementary planting (Table 4).

TABLE 3. National Forestry Board recommended planting levels for central Finland by site type[a]

Method: Species	Seedlings/ha	Site
Seeding:		
Pine	5000+	*Cladonia-Calluna* type
		Vaccinium type, fine-textured
		Vaccinium type, poor moraine
Planting:		
Pine	3000	*Myrtillus* type, poor
	2500	*Vaccinium* type, fertile moraine
	2200	*Vaccinium* type, poor moraine
		Vaccinium type, fine-textured
Spruce	2000	*Vaccinium* type, fertile moraine
		Myrtillus + *Oxalis* types
Birch	1600	*Myrtillus* + *Oxalis* types
Larch	1600	*Vaccinium* type, high elev.
Pinus contorta	2000	*Myrtillus* type, clay text.

[a] Adapted from Metsähallitus (1985)

TABLE 4. Recommended number of stems for stand establishment, minimum number of viable stems without supplementary planting being required, and minimum number of stems without replanting being required for normal and difficult-to-regenerate areas, by site index at age 100[a]

Species	Site Index	Recommended stems/ha at establishment	Minimum stems/ha without supplementary planting		Minimum stems/ha without retreatment	
			Norm.[b]	Diff.[c]	Norm.	Diff.
Pine	P28+	3000	2300	1800	1150	900
	P24	2600	2000	1600	1000	800
	P20	2300	1700	1300	850	650
	P16	1900	1300	1000	650	500
	P12	1700	1100	900	550	500
Spruce	S36+	2800	2300	-	1150	-
	S32	2500	2000	1600	1000	800
	S28	2300	1800	1400	900	700
	S24	2000	1500	1200	750	600
	S20	1700	1100	900	550	500
	S16	1500	900	700	500	500

[a] Adapted from SKSFS (Summary of Silviculture Laws, National Board of Forestry, Sweden).
[b] Normal regeneration.
[c] Difficult to regenerate.

Cleaning (removal of competing hardwoods) is mandatory under Swedish forest law, and is usually done when potential crop trees are 2-3 m tall. The law specifies the lowest number of unimpaired stems allowed (Table 5).

TABLE 5. Minimum number of unimpaired stems at 3 m without requirement to clean[a], and recommended number of viable stems following cleaning[b]

Species	Site index[c]	Minimum stems/ha to avoid cleaning	Minimum stems/ha after cleaning
Pine	P28+	2300	2600 - 3300
	P24	2000	2300 - 2900
	P20	1700	2000 - 2500
	P16	1300	1700 - 2100
	P12	1100	1400 - 1800
Spruce	S36+	2300	2600 - 3300
	S32	2000	2300 - 2900
	S28	1800	2100 - 2600
	S24	1500	1800 - 2300
	S20	1100	1600 - 2000
	S16	900	1400 - 1700

[a] Removal of competing hardwoods.
[b] Adapted from SKSFS (Summary of Silviculture Laws, National Board of Forestry, Sweden).
[c] Site index at 100 yr.

3.3 Stock

The current trend is away from bareroot stock and toward container grown stock. The number of different containerized seedling systems being used in practice has been growing steadily in recent years (Samuelsson 1985). The use of large stock (e.g., Enso pots) has increased slightly. In southern Sweden, where competing vegetation problems are evident, large caliper is considered to be more desirable. Planting a smaller number of "oversize" seedings (i.e., up to one litre rooting volume) on brushy sites immediately following harvesting may be an alternative to conventional stand establishment using smaller container seedlings (Brunberg *et al.* 1986). Some use is made of cuttings on highly productive sites where there is a lack of genetically high quality material. Research on seedling physiology is being increased (SJFR 1985).

4 HISTORICAL DEVELOPMENT OF SITE PREPARATION

Prior to the 1950's it was thought that cutovers in Sweden and Finland would regenerate naturally. Early artificial regeneration measures, such as spot and broadcast seeding and planting, were small scale. By the 1950's it was recognized that the pace of regeneration must be accelerated. Since nursery production was limited, natural regeneration and direct seeding were the common methods of reforestation.

Prescribed burning, which removed slash and facilitated access, was the predominant method of site preparation through the 1950's. Many examples of successful regeneration following burning date from this period when sites that were easy to treat were readily available. Prescribed burning declined at the end of the 1950's because of limited availability and high costs of labour, insufficient exposure of mineral soil, problems with variable weather, insurance, and the incidence of *Rhizina undulata* and other factors.

Patch scarification was originally carried out manually or with horse-drawn implements. In 1952, an agricultural tractor was used, pulling an Imset scarifier. Following the development of machines that could operate in rough forest terrain (i.e., skidders), mechanized site preparation was introduced. Patch scarifiers (e.g., SFI, Sinkkilä I, Leno) dominated site preparation through the 1960's, and mechanical site preparation became widespread with the introduction of forwarders.

Although seedling establishment proved to be relatively successful in scarified patches (Häggström 1958, Tirén 1958), mechanical problems were experienced on rough terrain (Jahnke and Nilsson 1975), as well as flooding, matting of vegetation over the patches, and lack of sufficient mineral soil exposure. Patch sizes of 35-40 dm^2 were recommended (Bäckström 1971, Söderström *et al.* 1979). Today, patch scarification is still used on well-drained sites or on sites with thin humus, where it is desirable to maintain a large proportion of undisturbed humus.

Wing or double mouldboard plows were developed in northern Finland around 1965 as a means of facilitating access for sowing and planting. Plowing was used to break up impermeable or fine textured horizons and to improve micro-site drainage, but was not intended for large-scale drainage. It was also an important tool for sites with thick (inactive) humus. "Tilt"[3] plows were introduced to further enhance soil temperature, micro-site drainage, and control of competing vegetation. Since 1967, plowing has been the dominant form of site preparation in Finnish Lapland where soils are cold and wet, though it has been used throughout both Sweden and Finland. Its use has since spread to a variety of site types other than those with thick, raw humus or fine soil textures.

Disc trenchers were also developed in Finland during the mid-1960's. It was thought that freely rotating discs would overcome obstacles with less stress than would occur with patch scarifiers or plows. Continuous furrows provided good planter access and selection of planting spots. Early light disc trenchers were progressively strengthened as prime movers became more powerful.

By the end of the 1970's, plowing and disc trenching accounted for 43 and 50% respectively, of the site preparation in Finland, while disc trenching and patch scarification comprised 44 and 50% respectively, of treatments in Sweden (Kaila & Päivänen 1981). Disc trenching has dominated site preparation practice in Sweden and south and central Finland into the 1980's. Despite earlier research that indicated positive effects with planting in elevated positions, site preparation has commonly provided planting positions that are below the general ground level (e.g., Berg *et al.* 1981). Disc trenching, which provided such below-ground-level planting spots, has been routinely applied as an operational treatment over a range of site types without much consideration for micro-site requirements or long-term effects (Lundmark 1980).

The 1960's and 1970's were periods of increasing timber production and mechanization. High mortality from *Hylobius abietis* following the DDT ban created a demand for site preparation treatments with enough mineral soil exposure to reduce the risk of weevil attack. As a result, the intensity or harshness of treatments increased. Demand for substantial exposure of mineral soil for seedling establishment has recently been criticized as potentially detrimental for long-term growth.

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[3] Tilt plows place a berm of inverted duff, covered by mineral soil, on the adjacent undisturbed soil. The word "tilt" is derived from till or cultivate. "Tilt plow" is commonly used in translations from the Finnish language to designate large plows that form plantable berms or tilts.

Research carried out during the 1970's improved knowledge of the scientific basis of site preparation. Enhanced soil temperature, availability of water, improved aeration, and competing vegetation control were recognized as important factors influencing the effectiveness of mechanical site preparation. The role of nutrients, however, received relatively little attention. Increased knowledge of the biological aspects of site preparation promoted interest in elevated micro-sites.

The benefits of mounding have been known for a long time. In Germany, the "Lochhügelphlanzung" method of tree planting was recommended over a hundred years ago (Gayer 1880). Buss (1932) and Ovsjankins and Kaninskaja (1960) described successful planting experiments with mounds in Estonia during the 1930's. Mounding has been done in Fennoscandia for about 20 years, using the excavated soils from ditching (Laiho and Kinnunen 1985). However, the technical and economic problems of creating continuous mounds discouraged the development of mounding implements. In the early 1970's, favourable results from planting in elevated plow tilts generated interest in raised planting spots, created without the radical soil disturbance associated with plowing (Söderström 1977). The first prototype mounder was produced in 1974.

Mounding has been slow in gaining popularity in a market dominated by disc trenching. It is perceived by some foresters as providing inadequate mineral soil exposure and requiring complicated planting instructions. Stumps, stones, and slash may impede mounding scoops and raise mounds above the soil, leaving undesirable air pockets. Mounds may be difficult to prepare on very fine-textured soils, which may also erode, exposing roots (Martinsson 1985). Climatic conditions with periodic drying or coarse-textured soils are not appropriate for mounding. Despite these limitations, Bäcke *et al.* (1986) have suggested that half of the forest area in Sweden is suitable for mounding (cf. Berg and Samuelson 1982).

In Finland, the desired long-term height of mounds is judged to be 20 cm (Mälkönen 1972, 1986). However, very good results with 10-cm mounds have been obtained in Sweden (Söderström 1976; Söderström *et al.* 1978; Berg *et al.* 1981; Örlander 1984, 1987, Martinsson 1985; Edlund and Jönsson 1986; Marek 1986; Charlesworth[4]).

[4] Charlesworth, E. 1983. Anpassning av Bräcke Kultivatorn och högläggaren till olika ståndorter och markberedningshinder (Adaptation of the Bräcke cultivator and mounder to different site types and site preparation obstacles). Unpublished manuscript.

5 CURRENT TRENDS

5.1 Sweden

The present trend in Fennoscandian site preparation is toward greater diversification of treatments. Criticism of "harsh" treatments and concern for long-term production have contributed to a "green renaissance" and an awareness that greater attention should be paid to knowledge of biological processes. "Site-adapted forestry" has been discussed since the beginning of the 1980's in Sweden. With the use of methods appropriate to each site emphasized (Figure 2), the productive potential of each site is then realized and the risk of failure is reduced. Site preparation, tree species and stock type, for example, should be appropriate to the biophysical characteristics of each site.

FIGURE 2. An example of "site-adapted" forest cultivation. Adapted from Fryck (1986). Illustrated by J. Fryck. Used with permission of Skogsarbeten.

It is commonly known that reforestation results are relatively poor on moist, rich sites (e.g., Gemmel and Örlander 1984). Consequently, when site preparation treatments suitable for average sites are used as blanket treatments across a variety of sites, the poorest results may occur on the most productive sites and the best results on less productive sites. Recent recommendations to improve regeneration results include better adaptation of site preparation treatments to site qualities (Anon. 1986b).

Simulations with recently developed production models (Ekö 1985, Näslund 1986) indicated that production could be increased by 1.0-1.5 m^3/ha per year with refined treatment applications (Lyngfelt and Nilsson 1985). Furthermore, calculations have indicated that the most intensive reforestation methods produced the least costly wood. Lyngfelt and Nilsson (1985) calculated that moving machines and varying

treatments to obtain improved results would be less expensive and would produce greater volumes of wood at maturity than would supplementary planting, which is likely to be necessary following less adapted treatments.

Following the central European experience (e.g., Rehfuess 1978; Ross and Malcolm 1982), the Fennoscandians are increasingly interested in the long term effects of site preparation. Some studies indicate substantial losses of nutrients through rapid mineralization and leaching following harsh site preparation (e.g., Lundmark 1977; Lundmark and Nömmik 1984; Rosén and Lundmark-Thélin 1986; Johansson 1987; Kubin 1987). Hence, it is desirable to preserve the nutrient capital in the humus layer and maintain the disturbed humus area or exposed mineral soil at a minimum (Lundmark 1980; Bäcke *et al.* 1986). An exception may be on wet, fertile sites.

An important criterion for assessing the effectiveness of a site preparation implement is the capability of making adjustments to provide alternative treatments, including elevated planting spots. Type or degree of cultivation is varied by adjusting downward pressure, disc angle, rotation speed, and continuity of preparation. Machines are now being simplified so that a number of treatments can be selected. The ability of site preparation equipment to provide alternative treatments is rarely fully used in practice because knowledge of biological requirements is still inadequate.

Recognition that site-adapted forestry requires competent field personnel has prompted improved training and a shift away from "cookbook" type guidelines. The Swedish National Board of Forestry and all the large companies have initiated training programs that use field excursions, books, and videos to increase the biological awareness of field personnel. Planters are also trained in some cases. Operator training courses offered by equipment manufacturers may include biological aspects of reforestation.

Planning units for silvicultural treatments are decreasing in size and may be as small as a quarter of a hectare (Lyngfelt and Nilsson 1985). The size of the smallest area that can be treated economically and practically, however, is still uncertain (Fryk 1986). Systems for planning and handling the increased flow of information, including following up and evaluating the whole process, are also coming into use.

5.2 Finland

As in Sweden, Finnish reforestation is moving toward more alternative and site-specific treatments.

Future directions can be interpreted from the long-term program for forestry presented in the Forest 2000 Program proposed by the Finnish Economic Council of the Ministry of Agriculture and Forestry (Anon. 1985b). The report suggests that the total annual cut could be increased by 650 000 m^3/yr. Some of the assumptions for input/output calculations are: thinnings could increase considerably; site preparation could increase and use softer technology; silviculture and stand improvement treatments could change considerably; the proportion of natural regeneration could increase; and the area fertilized could be doubled (Anon. 1985b).

The concept of "regeneration chains," that is, viewing forest regeneration as a whole rather than as separate entities (Parviainen and Lappi 1983), has been discussed. This idea has been incorporated into the Metsäteho model for evaluating reforestation techniques (see next section below).

5.3 Regeneration Cost Accounting

Although harvesting costs are carefully calculated, some Fennoscandian foresters consider the cost accounting of regeneration projects to be inadequate. Currently the cost of site preparation machinery or the cost per hectare of treatment and planting are common methods of costing regeneration projects without measuring success in terms other than survival. Some economic assessments of stand treatments are shown by Olsson (1986).

Expensive initial treatments may be the most cost effective when growth and development are considered. Edlund and Jönsson (1986) found mounding to be 50% more expensive than patch scarification at establishment. However, height development 8 years after planting gave cost per metre values of SEK 0.40, SEK 0.51, and SEK 0.61 for trees planted in mounds, without treatment, and in scarified patches, respectively.

In Finland, Metsäteho (the Work Study Section of the Central Association of Finnish Forest Industries) is developing a stepwise model for evaluating costs of different regeneration methods (Figure 3). The total cost of all activities in the regeneration chain can be compared at a simulated height of 5m. The model is based on operational reforestation data and best estimates. The inclusion of both biological and economic input allows the long-term effects of treatment costs to be compared. The model demonstrates the importance of considering effects of initial treatments in relation to the whole regeneration phase. The model is designed, however, to be an aid to silvicultural decision-making rather than a method of generating prescriptions.

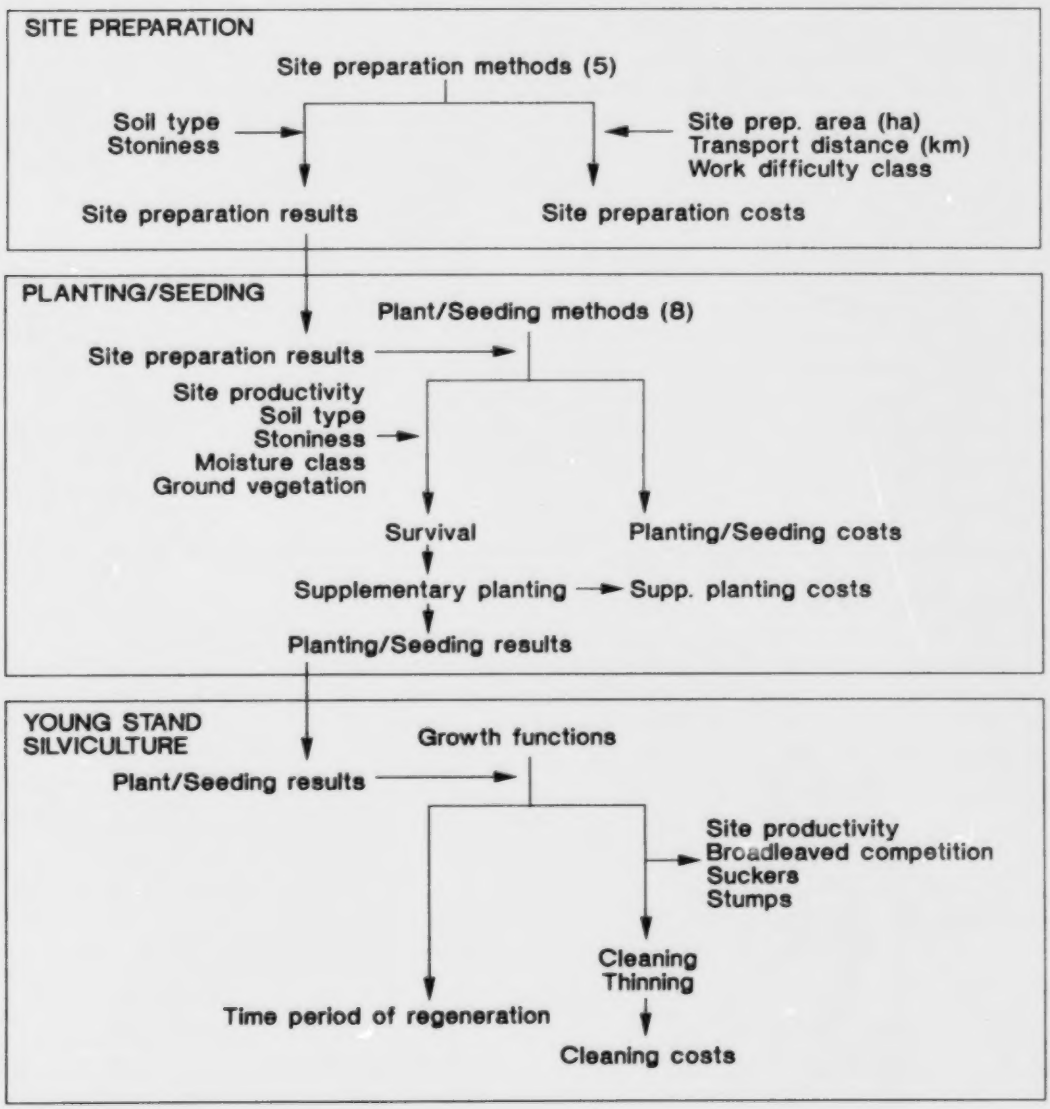

FIGURE 3. Schematic illustration of Metsäteho system for calculating comparisons among stand establishment treatments. Adapted from Hämäläinen *et al.* (1986).

6 MECHANICAL SITE PREPARATION EQUIPMENT

This section describes the development and method of operation for some of the main Fennoscandian site preparation implements that are suitable, or potentially suitable, for use in Canada. Addresses of the manufacturers and distributors are listed in Appendix 1. Technical details for the six main implements reviewed are presented in Appendix 2. Summaries of some Swedish and Finnish work studies are included in Appendix 3. Productivity rates in British Columbia for most of the implements reviewed can be found in Maxwell (1987).

6.1 Bräcke Mounder

Objective

To provide raised planting spots on inverted humus mounds (mineral soil cappings above inverted surface organic matter) or mineral mounds (mineral soil above mineral soil), or planting spots in scarified patches.

Background

The Bräcke mounder (Figure 4) was derived from the Bräcke Patch Scarifier which had metamorphosed from the original SFI Scarifier. Professor Söderström (Swedish University of Agricultural Sciences) had urged Robur Maskin AB to develop the first automatic mound-forming implement in 1974. The 2-row Bräcke Patch Scarifier creates intermittent planting spots with a minimum of site disturbance (cf. Masters 1978; Bamsey 1985a; Ryans 1986). A scoop was added behind each mattock wheel to scrape up soil from the scarified patch and form the mound (Figure 5). Only 10 units were produced in the 5 years following the mounder's commercial introduction in 1976. Various modifications to the patch scarifier have since occurred. In 1986, a "flipping" mechanism was added to lift the scoops to avoid scraping the tops off the mounds (Figure 5).

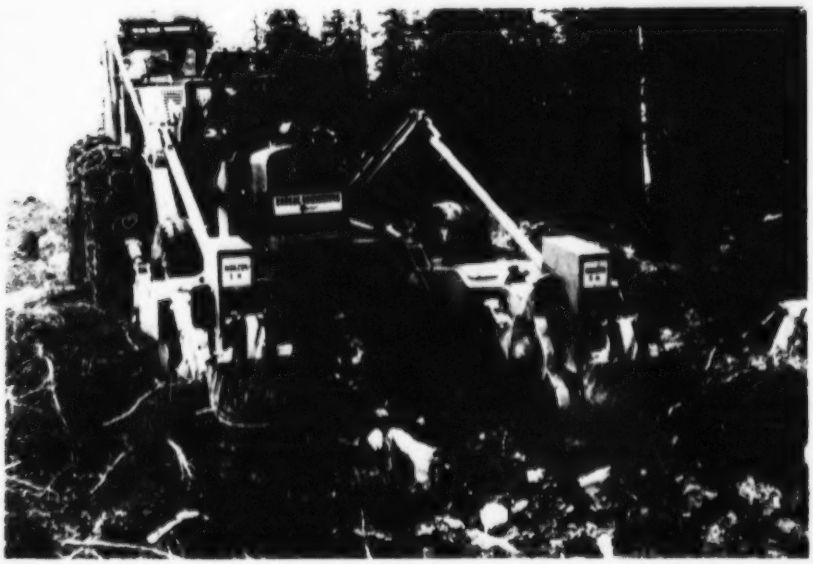

FIGURE 4. Bräcke Mounder. Photo: Robur Maskin AB.

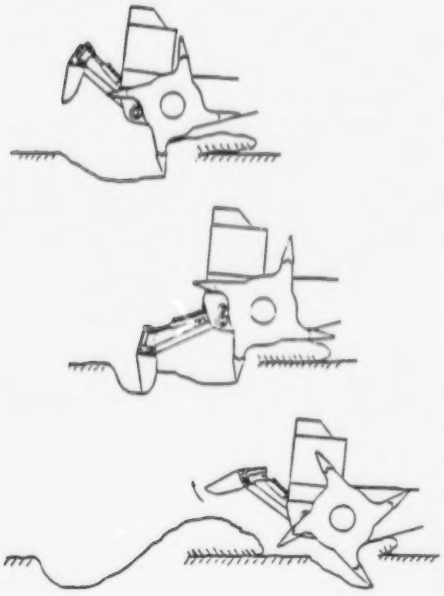

FIGURE 5. Mound-forming and flipping scoop of Bräcke mounder. Adapted from Robur Maskin AB.

Method of Operation

Components: **Mattock wheels:** 2, each with 3, 4, or 5 pairs of tines
Mounding scoops (shovels): 2, spring-loaded, hydraulically operated with power supplied by a 26-kW Deutz diesel motor mounted on the mounder frame; each scoop is mounted behind and synchronized with each mattock wheel
Road wheels: 2 with 30 x 60 cm, 16-ply tires
Drive chains and sprockets with 15/17 to 17/19 teeth

Mounting: Towed behind prime mover by winch coupling into bell housing mount bolted or welded to the prime mover; mounder can be paid out and winched in

The Bräcke Mounder scoops are integral attachments mounted directly behind the mattock wheels of a modified 2-row Bräcke Patch Scarifier. The scarifier's road wheels are linked by chain drives and sprockets to the mattock wheels so that their rotation is slower than that of the road wheels. The mattock tines are intermittently dragged through the ground to expose mineral soil by peeling off the surface organic matter which is deposited as a "divot," upside down in front of the forward edge of the mineral soil patch.

The 19-tooth sprocket gives the highest speed of mattock wheel rotation and consequently the shortest patch length and greatest number of patches per unit length of travel. The 15-tooth sprocket gives the longest patch and the greatest distance between patches. Changing the chain drive to another sprocket is not an adjustment which can easily be made to accommodate variation within a treatment block.

The scoops, which are actuated by cams on the sprockets, scrape about 20 L of soil from the exposed mineral soil patches. Adjustments allow this soil to be dropped onto the inverted surface organic matter beyond the forward edge of the exposed patch to form an inverted humus mound (Figure 5). Alternatively, the accumulated soil can be dropped onto the mineral soil at the forward edge of the patch to form a mineral mound. This adjustment could be made to accommodate site differences as small as a few hectares in extent, although this has not been done in standard practice.

The 4-tine mattock wheel, which is most commonly used in Sweden in conjunction with the 17-tooth sprocket, forms mounds or patches at approximately 2 m spacing along rows. The standard distance between rows is 2 m. The 3-tine mattock wheel with the 15-tooth sprocket produces patches at approximately 3 m spacing. Speed of travel must be relatively high for the 3-tine sprocket wheel to function effectively with the 15-tooth sprocket. The 5-tine mattock wheel with the 19-tooth sprocket forms the greatest number of patches per unit distance of travel.

Being a towed implement, the Bräcke Mounder has limited ability to back up. The mounder can be released, allowing the prime mover to traverse difficult terrain (e.g., wet spots, short steep slopes) and then winched in again. It can also operate while being winched in, so that the ground need not be left unprepared.

Robur Maskin AB has developed a simple procedure to evaluate work quality, so that the most appropriate machine settings and ground speeds can be determined for different ground conditions[5]. The manufacturer recommends that the operator use this procedure when starting on a new treatment block. Adjustments can be made to one side while the other is kept constant for comparison. Both sides are set at the optimum settings when these have been established.

Canadian experience with the Bräcke Mounder or comparable mounds is reported by Sutton (1984), McMinn (1985), Draper *et al.* (1985), Zroback (1985) and van Damme (1987). Appendix 3.1 contains summaries of Swedish work studies by Adelsköld (1986) and Adelsköld and Hallonborg (1986a).

6.2 HMF SCARIFIER/SINKKILÄ II

Objective

To provide inverted humus mounds (inverted surface organic matter capped by mineral soil), mineral soil patches or intermittent furrow planting spots.

Background

Mr. Aare Sinkkilä, one of the founding fathers in the mechanization of Finnish forestry, started by forging tanks into forest tractors following World War II. The Sinkkilä Patch Scarifier was a dominant site preparation machine in Finland during the 1960's and 1970's. Its long tined mattock wheels were hydraulically braked. The Sinkkilä II prototype was developed in the early 1980s in response to interest in machines able to make mounds (Figure 6).

In 1984 Teräskomponentti KY produced two prototypes. Serial production began with eight units in 1985 and six in 1986. Three units have been tested in Sweden and one each in Canada and Great Britain. Teräskomponentti KY is a relatively small steel fabricating company with little experience in forestry machines. The Sinkkilä II has been renamed the Tunnori in Finland, the Donhög in Sweden, and the HMF (Humus Mound Forming) Scarifier in Canada.

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[5] Charlesworth, E. 1983. Anpassning av Bräcke Kultivatorn och höglaggaren till olike ståndorter och markberedningshinger (Adaption of the Bräcke cultivator and mounder to different site types and site preparation obstacles). Unpublished manuscript 52 p.

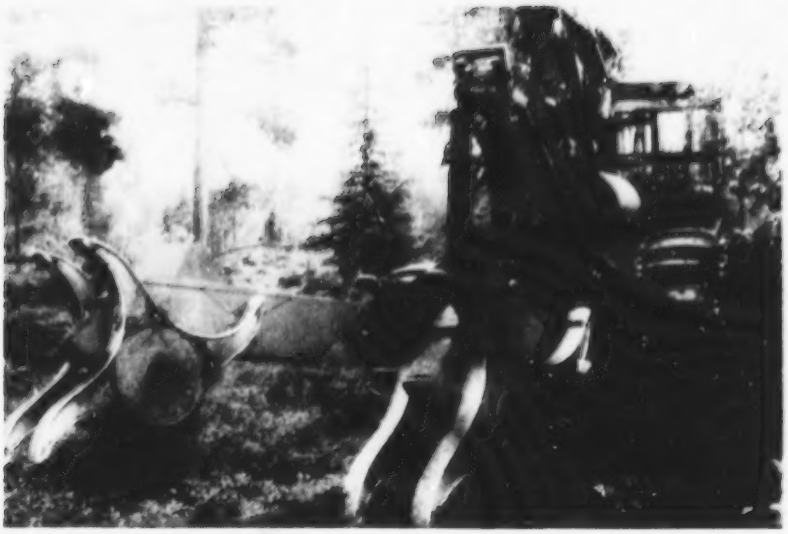

FIGURE 6. HMF Scarifier. Photo: J. Hunt.

Method of Operation

Components: **Ripper wheels:** 2, each with 4 pairs of 85-cm tines
Hydraulic braking (controlled from cab): stops rotation of ripper wheels. **First setting:** stops ripper wheels at 27°, 19°, or 11° before vertical, causing digging or dragging of ripper wheel tines; **second setting:** stops ripper wheels 26° past vertical, compressing mounds

Mounting: The pair of arms supporting the ripper wheels are attached directly to the prime mover with little or no modification required

The ripper wheels attached to each arm turn freely until braked (Figure 7). Braking at 11° forms shallow scalped patches or furrows, the length depending upon the braking time. Frequent short patches are formed with a short braking time. High or shallow mounds are formed according to angle and duration of braking. Braking at 27° with a long time setting causes the teeth to dig deeply and accumulate soil to form a large mound. Soil slides up the teeth until the brake is released, when the continued forward motion of the implement dumps the soil in an inverted humus mound capped by mineral soil. The second braking setting causes the "armpit" between the bars of teeth to compress the mound. Also, when the machine is going uphill the second braking serves to prevent the mound from falling backwards. Braking at 19° with a short time setting makes small inverted humus mounds.

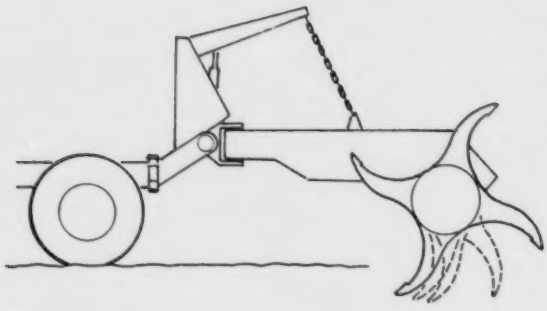

FIGURE 7. HMF Scarifier with 1985 model ripper wheel, showing three braking positions for Step 1 and one braking position for Step 2. The corresponding angles against a vertical line are 27, 19, 11, and 26 degrees, respectively. Adapted from Adelsköld (1986). Illustrated by U. Carne, used with permission of Skogsarbeten.

Hedin (1987a) and Appelroth (1986b) have evaluated the HMF Scarifier. Appendix 3.2 contains work study summaries by Adelsköld (1986), Adelsköld and Hallonborg (1986a) and Hämäläinen (1987).

6.3 Marttiini AKLM 190 Plow

Objective

To provide a variety of planting spots, from raised berms to exposed mineral soil in continuous or intermittent strips; and to provide improved micro-site drainage.

Background

Large forest plows developed in the 1960's formed "terrace" or "shoulder" micro-sites. Good results from planting in elevated tilts (berms) led to the development of tilt plows (V plows) with firmer tilts. Adjustments for the plow height and angle on the older plows (e.g., KLM 240) were made manually. The hydraulically adjustable AKLM 190 was introduced in 1981 (Figure 8). Further changes to the plow shape reduced the amount of retained mud, and shock absorbers gave more even results.

FIGURE 8. Marttiini AKLM 190 Plow in travel position (upper) and at working height and angle under hydraulic control (lower). Photo: Marttiini Co.

FIGURE 9. Lifting the Marttiini AKLM 190 Plow to remove debris (upper) and Marttiini AKLM 190 V prototype for wetland drainage (lower). Photo: Marttiini Co.

Method of Operation

Components: V-plow which can be hydraulically raised or lowered
Road wheels: 2 with 600 x 26.5 cm 16-ply tires with springs

Mounting: Direct coupling, towed behind crawler

The plow is supported while operating on two rubber-tired wheels (Figure 8). The angle of the plow and the depth of plowing is controlled by hydraulic cylinders on the articulated coupling arm. The spring suspension of the wheels reduces shock while the plow is operating.

At maximum depth, the Marttiini AKLM 180D can make a 32 cm deep furrow flanked by 18 cm high tilts, centred 180 cm apart. The tilts consist of inverted organic matter covered by mineral soil. Raising the plow can give shallow plowing with a 15-20 cm deep furrow and 12-cm tilts, 210 cm on centre. Surface plowing, by further raising the plow, can give a 250 cm wide strip of mineral soil flanked by 10-cm tilts, 320 cm apart. Winged screefers can be extended, exposing mineral soil by removing only the surface organic matter. Heel plowing can form two shallow trenches 200 cm apart and flanked by shallow berms.

All hydraulic adjustments are made from the cab. The plow can be raised to drop accumulated slash (Figure 9). The angle-regulating cylinder can be used to push the prime mover forward with a thrust of 20 tons if it becomes bogged down. The road wheels act as a trailer for moving the plow from place to place (Figure 8).

Another model, the Marttiini A-200 Terrace plow, may be used for "shoulder plowing". It creates flat, exposed mineral soil terraces (adjacent to the berm), rather than sloping tilts. This style of plowing was used in Finland before tilt plows. Planting in the terrace close to the berm was thought to be beneficial in places where berms may dry out.

The AKLM 190V, a new prototype which was introduced for wetlands, is power-driven from behind (Figure 9). An additional 50-kW hydraulic pump is required. The AKLM 190V is said to have good flotation and power to assist the prime mover.

Canadian studies on the Marttiini KLM 180 and 240 are reported by Mattice (1980) and Bamsey (1985a). Appendix 3.3 contains summaries of the manufacturer's description of the types of planting spots prepared and a study by Adelsköld and Hallonborg (1986a). Appelroth[6] and Hämäläinen and Kaila (1987) have also studied the AKLM 190.

6.4 Donaren 180D, 280 and 870H

Objective

To provide a range of planting spots, from those sunk in mineral soil furrows to those somewhat raised in partially overturned and mixed berms, in continuous or intermittent (Donaren 280) strips.

Background

The Donaren 180 was originally developed by the Finnish TTS company in collaboration with Domänverket (the Swedish state forestry company). Prototype FIAB and TTS trenchers were used in the design by the Swedish developers. The original design, which had hydraulic cylinders for inward/outward as well as upward/downward movement of the arms supporting the discs, was patented in 1976. Hydraulic down-pressure increased ground penetration and ease of adjustment to different site conditions.

The Donaren 180 was made in Finland until 1979, when production was taken over by Nordfors Teknik in Sweden. Power rotation was added in 1980 with the 180D model (Figure 10). Serial production of powered trenchers began in 1981. Since 1984, it has been manufactured by Skogsbruksmaskiner AB.

A Canadian adaptation which became standard in 1986 is a scraper welded to the upper arms to remove slash from the discs. Slash can also be removed by reversing the direction of disc rotation, a feature added in 1985.

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[6] Appelroth, S-E. 1985. Work study of the AKLM 190. Inter-Nordic Working Group (NSR) Meeting, Nov. 25, 1985, Ås, Norway. Unpublished Report.

FIGURE 10. Donaren 180D disc trencher. Photo: Skogsbruksmaskiner AB.

By 1987, about 200 Donaren units had been manufactured, 7 of which had been exported to Canada.

Method of Operation

Components: **Arms:** 2, with 1- to 2.75 m preset spacing, with welded stops
Discs: concave with 10 teeth and replaceable tips mounted parallel to direction of rotation; variable speed to 30 rpm

Mounting: Attached to prime mover, modification may be needed; adapter required if prime mover frame is greater than 80 cm high; removal of winch may be necessary on some skidders

The teeth of the discs rip the soil surface to expose a sloping strip of mineral soil bordered on the upper side by an irregularly overturned and partially mixed berm of surface soil. Discs turn in the direction of travel. The preset angle of the discs gives a relatively "harsh" (wide and deep) amount of mineral soil exposure. Downpressure settings control depth. The powered rotation of the discs aids penetration of slash accumulations. Discs are concave and smooth inside to reduce accumulations of mud. The sharp edges of the discs facilitate cutting of grass mats, but may cut into large slash which may then be dragged along. Meters in the control box monitor cultivated distance so that the number of seedlings required can be accurately estimated. The trencher's arms can be raised for sharp turns, backing up, and "deadheading" up steep slopes.

Studies of the Donaren 180D disc trencher in Canada have been undertaken by Ryans (1982), Bamsey (1985a, 1985b), Puttock and Smith (1986), Gibbard and Sutherland (1987), and Spaans (1987). The Donaren 180D and the driven TTS Delta disc trenchers have been compared in northern Saskatchewan[7]. Appendix 3.4 contains a summary of Adelsköld and Uggla's (1986) work study.

Donaren 280

The Donaren 280 can be used to prepare patches and intermittent or continuous trenches. For patches and intermittent trenches the control panel is set to raise the arms at predetermined intervals. Intermittent operating is suitable for dry to moist sites to reduce the area of disturbed soil, and for slopes to reduce erosion. On wet soils where drainage may be desirable, the Donaren 280 can provide continuous trenches. It is, consequently, a versatile machine capable of sufficient site adaptation to suit many site conditions in Sweden.

Donaren 870 H

A prototype Donaren mounder, the 870 H (Figure 11), was developed in spring 1987. It consists of the same body and arms as the Donaren 180D, but powered, vertically rotating ripper wheels or toothed scoops replace the discs. The digging principle is the same as the HMF Scarifier (Figure 7). The ripper wheels have three braking positions at Step 1 for digging, and one braking position at Step 2 for compacting the mound formed at Step 1. Mound size is controlled by the angle of the ripping teeth, braking distance, and downpressure. The heavy ripper wheels are supported by hydraulic pressure. The degree of downward pressure is controlled by releasing the lifting pressure on the ripper wheels.

FIGURE 11. Donaren 870 H mounder. Photo: Skogsbruksmaskiner AB.

[7] Sidders, D., M. Adamson and B. Sutherland. 1985. Unpublished Report.

The distance between mounds can be set automatically or manually. Intermittent trenches, up to 10 m in length, can be formed by prolonged braking at Step 2. The arms are forced inward and upwards when an obstacle is encountered. They are returned to, and held in the working position by hydraulic pressure (70 bar). The distance between arms can be set with stops.

6.5 TTS Delta

Objective

To provide a range of planting spots, from those sunk in mineral soil furrows to those that are somewhat raised in partially overturned and mixed berms.

Background

The Finnish Work Efficiency Association (TTS) started developing site preparation equipment in 1954. Over 1000 units of various types have been produced since the 1960's, of which about 150 have been sold in Canada. Currently, 20-30 machines are imported annually. Over a million hectares have been site prepared in Finland, Sweden, and Canada by TTS equipment.

The TTS disc trencher was introduced in the mid-1960's. The early TTS 25, which was too light (at 2.5 tons) for the heavy slash, was superseded by the 3.5-ton TTS 35 in 1972. Since then, a variety of free-turning discs have been introduced to improve amount and certainty of mineral soil exposure. The passive TTS 35 was the standard TTS trencher for a number of years. It has been largely superseded by the TTS Delta (Figure 12) in Finland with the introduction of hydraulic downpressure and powered discs. The Delta name is derived from the triangular form that the disc arms take when lifted upward and inwards.

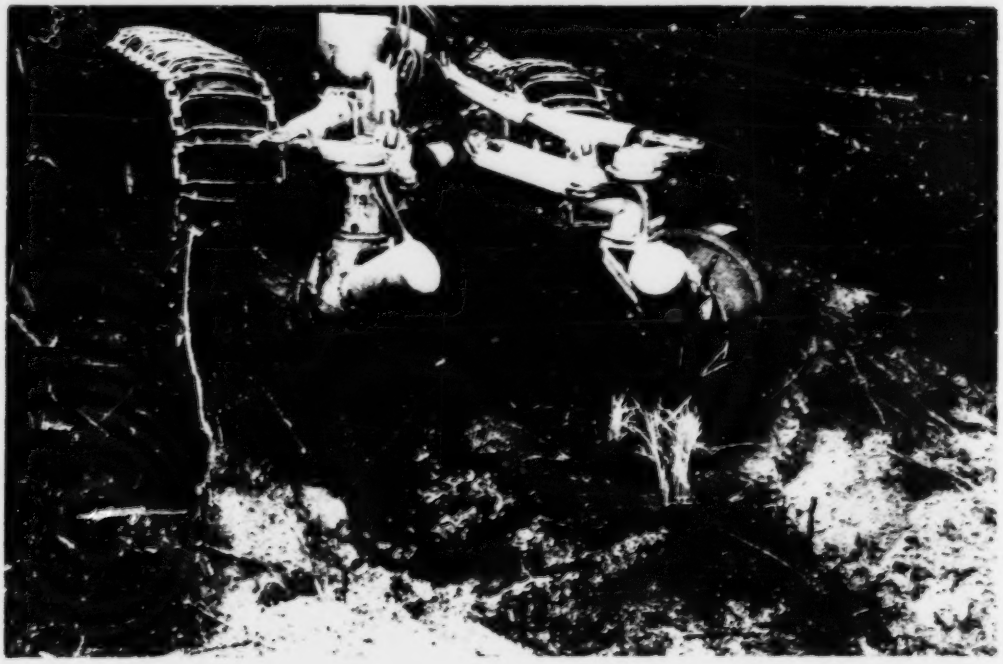

FIGURE 12. TTS Delta with hydraulically powered discs. Photo: Työväline OY.

The TTS 35H, with hydraulic downpressure on the independently articulated arms, was introduced in 1976 to provide increased work quality at high speed over uneven terrain. The arms were adjustable so that distances between rows could be varied from 1 to 3 m.

Hydraulically powered rotation was first tried in 1965. The hydraulic power requirement of the TTS 35HJ tiller introduced later was high (50 kW), because disc speeds were fast. Soil from the furrows tended to be scattered rather than forming a distinct berm. About 10 TTS 35HJ units were produced. The left and right arms on both the TTS 35H and HJ models can be interchanged so that the discs turn inward to form a single high berm. This form of preparation has been used in Germany (P. Haataja, pers. comm., TTS Rajamäki, Finland).

When power was added to the TTS Delta discs (a model that already had hydraulic downpressure), rotation speed was slower than that of the TTS 35HJ and could be varied. The TTS Delta, with or without powered discs, is now the main TTS production model. The TTS 35H and 35HJ models are still available on special order, but are heavier and more expensive than the TTS Delta. The latter, which allows variable distance between rows, can also be ordered specially. Meters inside the cab monitor the distance site-prepared.

Studies of TTS disc trenchers are reported by Armson (1978)[8], Masters (1978b), Appelroth (1981) Peterson (1985), Hedin (1985), Smith *et al.* (1985), and Puttock and Smith (1986). Appendix 3.5 summarizes Appelroth's (1986) work study.

Method of Operation

Components: **Discs:** 2 on independently articulated arms with hydraulic downpressure and adjustable disc angles; powered discs driven by variable speed hydraulic motor

Mounting: Fastened by 10 bolts through a flat plate, leaving skidder winch operable

The teeth of the powered discs, which turn in the direction of travel, rip the soil surface to expose a sloping strip (furrow) of mineral soil bordered on the upper side by a berm of irregularly inverted and partially mixed surface soil. The furrow can be 40-100 cm wide and 20-40 cm deep, depending on soil conditions, downpressure, and disc angle and size. The addition of power to rotate the discs principally facilitates slash penetration and has limited effect on the size of furrows. Extra cooling and oil capacity, and even an additional pump, may be required if the capacity of the prime mover's system is inadequate.

6.6 Other Developments by TTS

TTS 50HJ (Enso)

A 4-disc trencher for use on difficult-to-prepare sites was developed by TTS for Enso-Gutzeit OY (Figure 13). The first pair of non-powered discs removes debris and forms a small berm. This berm prevents the soil thrown up by the second pair of powered discs from being scattered. The 4-disc trencher is heavy (5000 kg), requires a large prime mover, and is expensive to operate. Adelsköld and Hallonborg (1986a) report that results were good but slash caused problems. Two prototypes, tested in Finnish Lapland, had an average productivity of 0.8 ha/hr. One unit is still in use in southeastern Finland.

TTS "Combi"

A combination of plow and disc trencher has been developed, allowing one machine to prepare a range of sites. It is, however, heavy and difficult to pull of soft ground. A few units are still in use.

Another combination model consists of front-mounted non-powered discs and a plow pulled behind the crawler tractor (Figure 14). The effects of driving over the disced trench have not been studied.

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[8] Armson, K.A. 1978. Site preparation in northern Ontario. Ont. Min. Nat. Res. Unpublished Report.

FIGURE 13. TTS 50 HJ. Photo: Työväline OY.

FIGURE 14. TTS combination plow and front-loaded disc trencher. Photo: Työväline OY.

TTS Mounding Delta

Initial attempts to develop a mounder with intermittently raised and lowered scrapers to mound soil in the trench were not fully successful. Depth was difficult to control and excessive power was required to lift the scrapers. After 5 years of additional research, rolling and pivoting instead of lifting scrapers was found to work successfully (Figure 15). These scrapers are attached to additional TTS Delta arms. The scraper wheels pivot at fixed distances to mound soil scraped up from the trench. The arms could also be set to scrape soil from the berm or to push mineral soil from the trench to the side forming mineral soil mounds above humus.

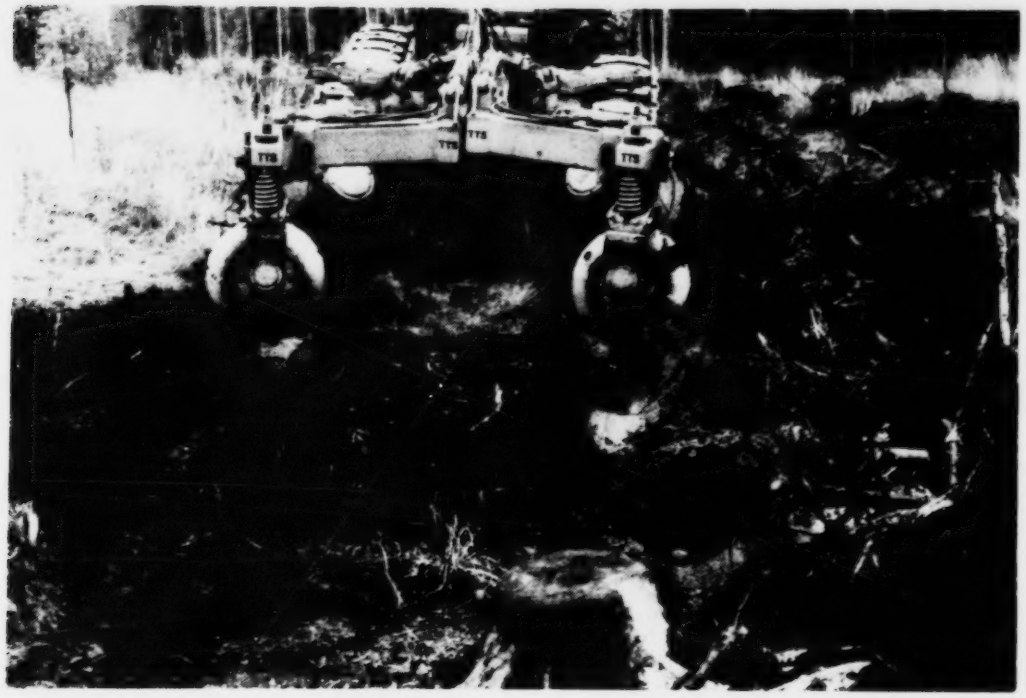

FIGURE 15. TTS Mounding Delta. Photo: Työväline OY.

All four arms can function independently and can be set for different distances and downpressure. With the discs raised, the rolling scrapers form patches or mounds; with the scrapers raised the unit acts as a normal disc trencher. The shortest distance between patches is 1 m. A combination of different adjustments can produce a great variety of planting spots.

The Mounding Delta weighs approximately 4000 kg and requires a 120-kW prime mover. The additional hydraulic circulation of 140 L (2 x 70 L) at 120 bar may require an accessory 50-kW engine. Existing TTS Delta units can be converted to Mounding Deltas by attaching the additional arms. Two units were tested in autumn 1986.

The ability of the TTS Mounding Delta to create various shapes and sizes of mounds and patches, as well as standard disc trenched furrows, should make it an attractive "multi-purpose" unit for site-adapted treatment prescriptions. The Mounding Delta is, however, a heavy and complicated machine that has not yet had appreciable operational use.

6.7 Wadell Cone Trencher

Objective

To provide a range of planting spots, from those sunk in mineral soil furrows or patches, to those raised in mounds of partially mixed soil.

Background

The Wadell Cone Trencher (Figures 16, 17) (Wadell Fräsen could be translated as Wadell Rotovator) was originally developed to expose strips of mineral soil. Rotation against the direction of travel was adopted to improve contact with the ground and effectiveness of screefing. Early investigations sought to establish the best shape and placement of the teeth. Favourable results were obtained by concentrating teeth toward the tip of the cone. Cone speed on early models was variable up to 30 rpm (not under load). After the Wadell was chosen in 1980 as the site preparation implement for the Silva Nova tree planter, further development had the benefit of the expertise and resources backing the planter. In 1986, adjustments for intermittent cultivation, change in cone angle, and increased rotation speed (to 40 rpm) were added. More recently, ability to rotate the cone in either direction was introduced. Design improvements included simplifying the controls to facilitate easier choice of treatment, and developing a component system to simplify trouble shooting and parts interchange. The electronics are concentrated in three sealed units (control box, micro-computer, and valve units), which are plug in/pull out.

Forty-five units have been produced, of which 12 are the "multi-phase" models.

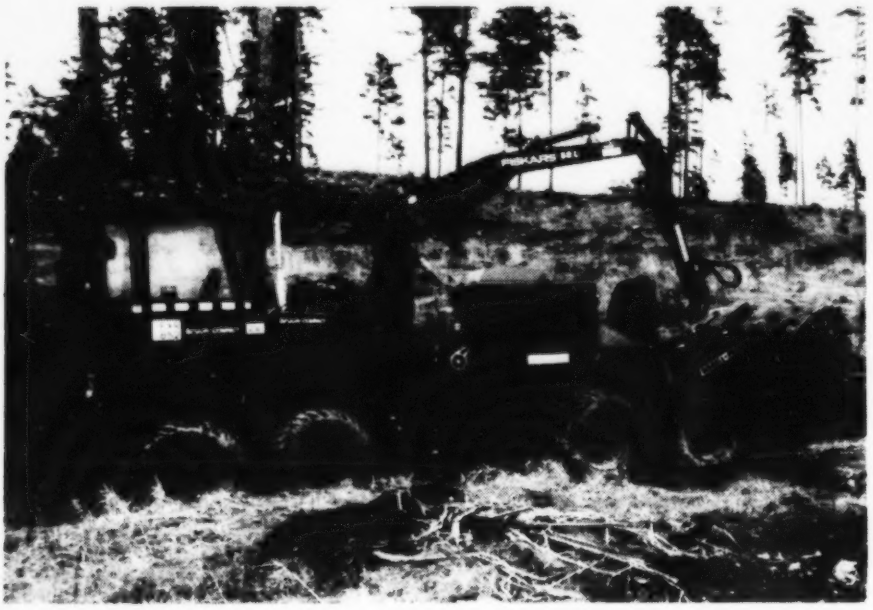

FIGURE 16. Wadell Cone Trencher mounted on a small forwarder with auxiliary motor. Photo: G. Wadell.

FIGURE 17. Wadell cultivating unit. Photo: G. Wadell.

Method of Operation

Components: **Arms:** 2, independently suspended; overload protection by sensor lifts cones up to 37° to avoid obstacles; the distance between arms is adjustable as an option
Cones: 2, with 32 replaceable teeth, powered for continuous or intermittent operation; **direction**: against direction of travel but reversible; **speed**: variable up to 40 rpm; **angle**: variable up to 18°

Mounting: Special adapter usually required

The two cones are attached to independently suspended arms which can be raised and lowered. The pressure exerted by the arms can be adjusted hydraulically from reduced pressure (lifting support) to increased downpressure. Powered rotation of the cones exposes a level or sloping strip of mineral soil, depending on the cone angle (Figure 18). Depth of the strip depends on the speed of rotation and downpressure on the arm. Rotation speed, however, has little influence when downpressure is high. Mounds may be formed with intermittent cultivation where fast rotation against the direction of travel and a sharp cone angle piles mixed humus and soil in front of the cones. The cones then rotate with the direction of travel, compressing the mound.

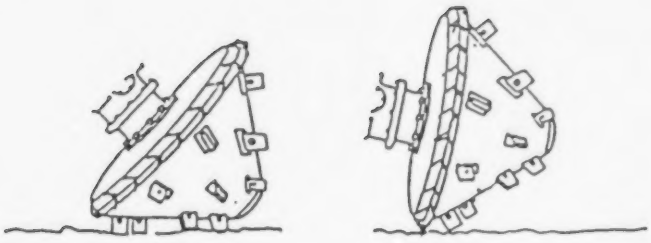

FIGURE 18. Cones of Wadell Cone Trencher showing range of angles.

With light slash, cones creep under the slash rather than rolling over it. When the slash is heavier, however, slash may be only slightly displaced and then fall back. Deflectors have been used on the Silva Nova tree planter to prevent slash from falling back into the cultivated trench. A better solution to the slash problem is being sought.

Work studies have been made by Gustafsson and Morenius (1980), Gyldberg (1986), and Adelsköld and Hallonborg (1986b) (Appendix 3.6).

7 ADDITIONAL EQUIPMENT REVIEWED

7.1 Excavators

Developments to increase the productivity of excavators for mounding are continuing in both Sweden (e.g., Brunberg and Fries 1985) and Finland.

7.2 FIAB MB25 Disc Trencher

The disc arms of the FIAB MB25 disc trencher slide inward on a bar rather than lifting upward when an obstacle is encountered. After the obstacle has been passed, the disc arms slide out again under hydraulic pressure. Consequently, the discs remain working, continuously in contact with the ground. The FIAB MB25 has hydraulic downpressure (up to 90 bar) and variable speed powered discs as an option. In 1986, an intermittent option was added. All functions are controlled from the cab. The unpowered model weighs 2200 kg; with powered discs weighs 2330 kg. The minimum power requirement for the prime mover is 115 kW. About 200 2-row FIAB units of various types have been produced.

Two prototype 4-row FIAB units have been constructed. The additional discs are supported by arms mounted on either side near the middle of the forwarder, and these work ahead of the rear wheels. The outer discs are 6.3 m apart. On easy terrain a Skogsarbeten study (Samuelsson 1986) found no difference in the quality of preparation by the inner and outer discs. Differences in treatment effects with differences in downpressure or disc rotation speed were not evident. Most planting spots were below ground level.

7.3 Sinkkilä III

The Sinkkilä III (Figure 19) is a lightweight (600 kg) site preparation implement under development by Mr. Aare Sinkkilä (Tuuves Ky, Tennilä, Finland). The thin, spring steel ripper teeth slice into and lift the soil, which is then inverted and compressed as the machine advances. Scalped patches can also be formed on another setting. Tooth length can be adjusted from 80 to 100 cm. Braking distance of the teeth is controlled mechanically. Maximum hydraulic pressure required is 15 bar. Prime mover requirement is 10 kW. Three or more units could be used behind a large prime mover.

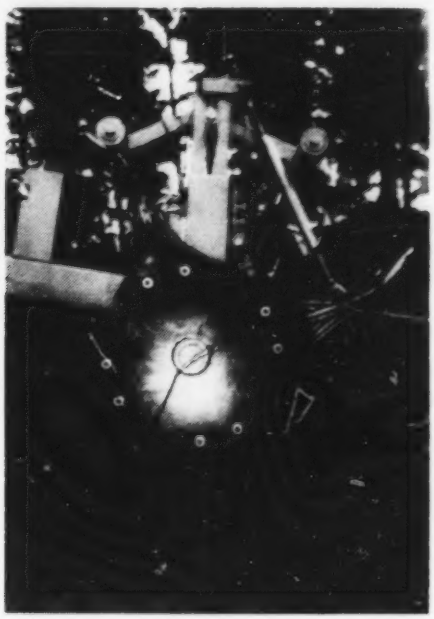

FIGURE 19. Sinkkilä III prototype mounted on an agricultural tractor. Photo: S.-E. Appelroth.

7.4 Brush Saw Screefers

A domed, toothed screefing head which removes surface organic matter to expose a mineral soil planting spot has been developed as a brush saw attachment at the Swedish University of Agricultural Sciences, Umeå. The attachment is also said to be capable of forming elevated micro-sites. Another unit developed by Nordforest AB makes a planting hole centered in 18 dm^2 of exposed mineral soil. The 8 cm long bits which make the hole are supplied in a diameter range (4, 5, 6 cm) to accommodate various container sizes. Productivity is said to be 2000 to 3500 planting spots per day. Brush saw screefers are not yet widely used, but have aroused considerable interest in Sweden.

7.5 Silva Nova Tree Planter

Recent developments suggest that the Silva Nova Tree Planter (Figure 20) could become fully operational within a few years. About one quarter of a billion (present value) Swedish Crowns (5 SEK = $1 Cdn) has been spent on planting machine development over the past 20 years in Sweden. Of the original three to five projects, only the Silva Nova is still under development (S. Berg, pers. comm., Skogsarbeten, Spånga, Sweden).

FIGURE 20. Silva Nova tree planter. Photo: G. Wadell.

Development of the tree planter that became the Silva Nova started in the mid-1960's. Forwarder mounted prototypes using patch scarification for planting spot preparation were tested in 1976. The Wadell Cone Trencher was adopted as the site preparation component in 1980. In 1982 Storebro Bruks AB took over development which had been initiated by a large forest company. The Silva Nova became operationally functional by 1983. In 1984 pre-serial machines were bought by the three biggest Swedish forest companies, who subsequently invested heavily in further developments and contributed valuable advice. A fourth company bought a unit for testing in 1985.

In 1986 soft grip ("hand") seedling handling replaced air blowing to transfer seedlings to the planting head. Air blowing caused some seedling desiccation and mechanical damage. A variety of seedling types can be used. A sensing system in the planting arm tests the softness/hardness of the planting spot at two depths. Planting depth can be controlled to within 3-4 cm. Seedling placement can be directed to various positions in the site-prepared profile. According to the manufacturer, seedlings can be planted at an average rate of 1400 per hour at a cheaper rate than hand planting. Under favourable conditions, as many as 1800 seedlings can be planted per hour.

8 BRITISH COLUMBIA PERSPECTIVE ON FENNOSCANDIAN TECHNOLOGY

The ultimate test of the biological effectiveness of site preparation equipment, whether imported or developed in British Columbia, is plantation performance. While favourable survival and initial growth are obviously prerequisite for plantation success, growth rate for a much longer period than the first few years must be at least commensurate with the capability of the site, before there is proof that the site treatment and the machine that created it are site adapted.

Unequivocal evidence that a machine is capable of site specific treatment cannot be obtained from evaluations or trials made in other countries. Trials must be followed on sites representative of local ecosystems for the time necessary to judge long-term effects. Import or development of new machinery cannot, however, wait that long. Inferences must be obtained from an understanding of conditions in the countries with technology to offer and from trials that demonstrate biological principles in the receiving environment.

The following assessments are based on evaluations of the applicability of Fennoscandian experience from a British Columbia perspective. This perspective has been gained through examination of plantation performance in the Boreal and Sub-Boreal Zones in British Columbia, elsewhere in Canada, and in Fennoscandia.

8.1 Bräcke Mounder

The Bräcke Mounder is capable of creating inverted humus mounds (mineral-capped inverted LFH layers on undisturbed ground), mineral mounds (mineral soil heaps on mineral soil), and scalped patches. Additional adjustments can alter the size and number of planting spots prepared per hectare. Since each type of planting spot can have a site-specific application, the Bräcke Mounder has the potential of being a versatile site-specific machine. Switching between inverted humus mounds and scalped patches can be done from the cab of the prime mover. Changing to mineral mounds requires adjustments that must be made at the mounder.

Raised planting spots are especially favourable on subhygric and hygric sites because elevation enhances seedling root aeration. Access by seedlings to the nitrogen of inverted LFH layers gives inverted humus mounds a favourable initial nutrient status (Draper *et al.* 1985). Inverted humus mounds may be especially good for fine-textured soil because seedling roots can exploit the friable, warm and nutrient-rich layer at the interface between the warm soil cap and the inverted LFH layers. Scalping by blades, patch scarifiers, or trenchers may be counterproductive in fine-textured soils because seedling performance is usually poor in compact subsurface soil. Seedling survival in dry climates, however, may be higher in mineral mounds than in inverted humus mounds (L. Bedford, pers. comm., B.C. Ministry of Forests and Lands, Victoria, B.C.). Survival may be improved by planting seedlings deeply in inverted humus mounds, even though some foliage may be buried. The value of long-rooted seedlings planted at normal depth is being investigated as a means of circumventing potential drought problems in inverted humus mounds.

Amount and depth of mineral soil capping can be important for seedling performance and for control of competing vegetation. McMinn (1985) found that white spruce seedlings planted in mounds with 12 cm of mineral soil cap were larger after four growing seasons than seedlings planted in mounds with 6- or 2-cm cappings. The 12-cm capping depth, however, should not be taken as an absolute value under all circumstances. Some sites may require deeper cappings to suppress competing vegetation; other sites may need less. Hedin (1987) indicates that "...the ability of the Bräcke Mounder to prepare mounds with greater than 10 cm of mineral capping was definitely site dependent and limited." Obstacles, such as stumps, boulders, and hard to penetrate subsurface soil, interfere with the amount of soil dropped onto the inverted LFH layers. Leblanc (1988) found that, in the Ontario clay belt, the balls of clay soil dug by the scoop did not always remain on the inverted layers. The versatility of the two-stage operation (its ability to form mineral mounds as well as inverted humus mounds) may be partially offset by its inability to place the mineral soil capping in the required spot under all circumstances. Leblanc also found that some 25% of the mounds were mineral soil mounds. This result suggests that the Mounder may not have been adjusted to maximize inverted humus mounds. Correctly adjusting the machine needs operator training and motivation to avoid potential problems.

The Bräcke Mounder has been somewhat overshadowed in Sweden by the popularity of powered disc trenchers. The amount of site disturbance produced by the Bräcke Mounder, especially when viewed at right angles to the direction of travel, seems small and perhaps inadequate to foresters whose perception of satisfactory site preparation is based on amount of mineral soil exposure. Swedish results, however, suggest that cost per metre of height of established seedling may be lowest for mounds (Edlund and Jönsson 1986).

Although the current model of the Bräcke Mounder seems to be limited by difficult terrain and mineral soil cappings are generally not deep, it is a rugged, versatile machine with an established record of usefulness for a variety of sites in Sweden. The estimate by Bäcke *et al.* (1986) that some 9.6 million ha of forest land in Sweden are suitable for mounding suggests that there is a substantial market opportunity for equipment capable of mounding. Where mounds with moderate mineral soil cappings provide satisfactory control of competing vegetation and good seedling performance, and where terrain and slash conditions are not too severe, the Bräcke Mounder should perform effectively in British Columbia.

8.2 HMF Scarifier

The HMF Scarifier can form inverted humus mounds and scalped patches. Change in mode can be made from the cab of the prime mover so that different types of site preparation can be done in a cutblock. Such versatility is desirable for site-specific prescriptions.

While the original Sinkkilä was a very successful patch scarifier, some question remains concerning the efficacy of the HMF Scarifier as a mounder in Canada. Accumulating soil with two teeth may not be as efficient as digging with a scoop in the variety of soil textures and moisture conditions in which mounding is desirable. Unlike a shovel, soil tends to slip around teeth so that a longer digging time may be required to accumulate a given amount of soil. Braking the ripper wheel for sufficient time to accumulate an adequate mineral soil capping may result in accumulation of extra surface organic matter. This extra surface organic matter is pushed together like a concertina and may form a loose foundation for mounds because of undesirable air spaces. Sides have been added to the tines by the Canadian distributor as a modification intended to improve soil accumulation.

Mounds have been observed in Finland from which Scots pine roots had not egressed during the three years since planting (R. McMinn, pers. comm., B.C. Ministry of Forests and Lands, Victoria, B.C.). Whether Sinkkilä mound formation restricts root egress is not known, since other reports of restricted root egress have not been found.

Under favourable conditions, most mounds made by the HMF Scarifier have more than 10 cm of mineral soil capping (Hedin 1987). The lower number of mounds per hectare formed by the HMF Scarifier compared to the Bräcke Mounder (Adelsköld and Hallonborg 1986a) is not a problem in British Columbia because the number required is lower than in Fennoscandia.

The considerable length of the HMF Scarifier attached behind the prime mover may cause excessive swinging and stress. Locally fabricated stops added by the site preparation contractor in British Columbia during 1986 stopped the arms from becoming enmeshed when traversing side slopes. The tradeoff between increased productivity with increased ground speed and accelerated wear is a consideration for equipment contractors.

Studies in Finland suggest that ground speed has little effect on work quality at the speeds tested (Appelroth 1986). The highest speed tested, however, may have been slower than is general in British Columbia.

Overheating of the hydraulic braking system caused malfunctioning of the HMF Scarifier in British Columbia during trials in 1986. The Canadian distributor considers that this problem has been corrected. It was suggested in Finland that the problem may have been caused by excessive ground speed because overheating was not recognized as a problem in Finland (M. Tolonen, pers. comm., Teräskomponentti Ky, Heinola, Finland).

Trial of the HMF Scarifier in British Columbia in 1986 had some of the problems associated with "orphan" equipment. Malfunctions were difficult to correct because English manuals were inadequate and no factory representative was present for the start-up period.

8.3 Donaren 870 H

Although still at the preproduction stage and therefore unlikely to be immediately available in British Columbia, the Donaren 870 H seems to have considerable potential as a site-specific site preparation machine. Similar in principle to the Sinkkilä HMF Scarifier in the use of a braking mechanism for digging or patch scarifying, it has the potential of using a toothed bucket-like implement for digging to make the mounds. Side mounting the digging implements (on arms which are interchangeable with the arms that carry the discs of the 180D and 280 disc trenchers) means that the Donaren 870 H can use a more effective implement for digging than tines separated by a mattock wheel. The Donaren 870 H has the advantage of being directly attached to the prime mover which, consequently, can readily back up. The prime mover, however, must have enough hydraulic capacity to operate the arms, or must be capable of carrying an auxiliary motor to generate adequate hydraulic power needed to operate the arms and digging device. Progress in testing the Donaren 870 H would seem worth watching so that a production model can be tried in British Columbia when available.

8.4 Disc Trenchers

The furrows created by disc trenchers provide a range of planting spots suitable for site-specific prescriptions. Planting spots at the bottom of trenches are suitable for well-drained xeric to submesic sites, but may become waterlogged on subhygric to hygric sites. Planting at the top of the trench provides a somewhat raised micro-site and seedlings have access to the nutrients in the overturned surface material in the berm. The partially mixed nature of the berms can stimulate luxuriant plant growth on sites prone to competing vegetation. Although this does not seem to be a significant problem in central and northern Fennoscandia and on relatively dry sites in southern Sweden, berms from disc trenching may not be biologically effective raised planting spots in British Columbia on sites with aggressive competing vegetation. Greater competing vegetation control on berms may be possible with low travel speeds, and with disc angles and downpressures that maximize the amount of mineral soil cast onto the berm.

A study in Alberta (Gibbard and Sutherland 1987) showed that the number of plantable spots in mineral soil increased by 13% when downpressure was increased from 0 to 25 bars. This increased number of planting spots occurred despite a slash load that was three times as great on the site where the greatest number of plantable spots were created. However, operators with area-based contracts may be tempted not to use downpressure because travel speed — and therefore hectares per hour — may be reduced, especially if the prime mover has insufficient power to supply the trencher with enough hydraulic pressure unless low gear is used. Obtaining the number and quality of plantable spots per hectare by rigidly enforcing standards that need low ground speed to achieve, could be reflected in higher bid prices.

Increased disc speed improves penetration of slash and may slightly increase width of exposed mineral soil (Appelroth 1986). Differences, however, are minimized at increased ground speed. At the travel speeds customary in British Columbia, speed of disc rotation may make little difference in furrow width. Moreover, the maximum rotation speed for the Donaren and Delta (40 rpm) is unlikely to control competing vegetation by sufficient comminution to prevent resprouting. Nominal rotation speed of the Madge Rotoclear which chops up competing vegetation effectively is 300 rpm. Such a speed effectively chops up and controls competing vegetation.

Changes in disc angle make more differences in the width of trenches in medium-textured than in fine-textured soil. The power available for downpressure seems insufficient to counteract the resistance of compact soil. Consequently, the ability to change disc angle may be an option on the TTS Delta which does not greatly affect work quality in fine-textured soils.

So far, operator preference in British Columbia seems evenly split between the Donaren 180 D and the TTS Delta. While less hose breakage, fitting replacement, and oil losses reduced estimated work cost for the Delta to $2-2.50/ha from $3-4/ha for the Donaren, other factors such as stress on machines, availability, wear on operating parts, ease of operation (e.g., the Delta must be stopped to change downpressure), and daily maintenance needs tipped the balance in favour of the Donaren for at least one site preparation contractor. Differences in seedling performance on the planting spots prepared by the two machines has not yet been assessed.

The option of discontinuous furrows offered by the Donaren 280 may be advantageous on slopes because the possibility of erosion is reduced. Since Swedish studies have shown that the number of plantable spots is not reduced by discontinuous trenching, this option could also be useful in British Columbia to reduce the intensity of scarification. Up to now, little attention has been paid in British Columbia to possible long-term deleterious effects of too much scarification. The perception in Sweden that dry sites with limited LFH depth can be over scarified should alert silviculturalists in British Columbia to the possibility that more extensive site disturbance could have more long-term adverse effects than necessary.

8.5 Wadell Cone Trencher

The flat strips or patches created by the Wadell Cone Trencher seem suitable for soils with moderate texture, not liable to waterlogging. The sloping mineral soil surface, formed when the cone is angled, is likely to be better adapted to mesic sites and subhygric sites because planting spots level with or above the general soil level can be chosen.

The small mounds formed by intermittent operation of the cone consist of mixed LFH layers and mineral soil. Unlike mounds covered with a thick mineral soil capping, the partially mixed mounds formed by the Wadell are more likely to promote growth of competing vegetation than to control it on subhygric to hygric, permesotrophic to eutrophic sites. Consequently, although the variable functions of the Wadell provide an opportunity for site-specific treatments, its reputation for providing site-sensitive levels of treatment warrants trial under British Columbia conditions before acceptance. For example, a light treatment that leaves some of the H layer in place might reduce frost heaving in fine-textured soils, but would have little effect in controlling vegetation on a subhygric, permesotrophic site. Inverted humus mounds with adequate mineral soil caps have been shown to be effective on such sites, and frost heaving has not been a problem in inverted humus mounds in British Columbia (McMinn 1985). Whether mounds with a deep mineral soil capping can be created by the Wadell Trencher has not been tested in British Columbia.

The technology of the Wadell Cone Trencher is relatively complex. The manufacturer, however, has designed the equipment for easy maintenance, incorporating, for example, replaceable electronic units. Some problems were encountered during 1987 trials, with the rubber tire shock absorbing system not withstanding the rigours of British Columbia operations. Swedish evaluations noted that, at full downpressure, nominal cone rotation speed was not maintained (Gyldberg 1986), meaning that the full range of potential adjustments may not actually be available. However, the full potential of this machine to deliver site-adapted treatments should be tested to determine the Wadell Cone Trencher's usefulness in executing site-specific prescriptions in British Columbia.

8.6 Marttilni AKLM 190 Plow

Plowing seems to have provided a solution to the problem of reforesting most cold, wet sites in Finnish Lapland. Long-term effects have not yet been fully established. A note of caution has been introduced by the occurrence of decline and death of pine regeneration on some sites (Tikkanen 1985). Disc trenching is increasing in popularity in northern Finland. Plowing, once the predominant method, is being decreased.

Plowing has been criticized as being an overly drastic treatment. The AKLM 190 was introduced as an adjustable, multi-purpose implement to counter such criticism. It can be adjusted to give "soft" scarification where needed. Operators, however, must be conscientious in using the adjustments to provide only the desired amount of disturbance. Use of plows in Sweden is restricted to wet or harsh climatic sites. In Alberta, Marttiini KLM 180 and 240 plows have provided elevated planting spots with good planter access and reduced competition in wide trenches (Bamsey 1985). Long-term effects are, however, still unknown. Problems with depth control, slash and stumps, flooding, grass on berms smothering seedlings and difficulty in retreating failed areas have been reported.

Plowing might be useful in British Columbia on very wet sites, such as those on which excavators are being tried. Whether the AKLM 190 Plow would provide a cheaper and biologically more effective form of site treatment than excavators will not be known until the comparisons are made under comparable conditions.

9 CONCLUSIONS

Sweden and Finland have a long history of intensive reforestation practices. The similarity of boreal forests should enable British Columbia forest managers to use this Fennoscandian experience to reduce the time and cost of developing intensive silvicultural methods. An understanding of the background of Fennoscandian forestry is necessary, however, for effective technology transfer, given the difference in environmental and management constraints between British Columbia and Fennoscandia. Methods are likely to require some modification for local, British Columbia conditions.

The infrastructure to facilitate mechanized silviculture is well developed in Sweden and Finland. The development of sophisticated equipment in Fennoscandia provides an opportunity for reducing duplication of development costs in Canada. Modification of imported equipment or the way in which it is used may be necessary because Canadian and Fennoscandian conditions are not entirely comparable. For example, heavy slash loadings after clearcutting overmature British Columbia forests may require clearing ahead of treatment, so that advanced site preparation equipment can operate effectively.

The recent emphasis in Fennoscandia on "site-adapted site preparation" can give impetus to the growing interest in site-specific prescriptions in British Columbia. Fennoscandian experience, for example, has demonstrated that the cost per metre of established plantations may be reduced by appropriate site preparation. Considerable emphasis is being placed on biological training for field staff and machine operators so that prescriptions and their execution can fulfill site-specific needs. There is also a growing awareness that long-term forest productivity may be impaired by "harsh" treatments which drastically disturb sites.

Site preparation implements that can prepare a range of micro-sites, including elevated planting spots, are increasingly favoured in Fennoscandia. Operator training and motivation are recognized as fundamental to the use of such equipment because optimum results will not be realized unless appropriate micro-sites for each condition are prepared. There is also awareness that greater biological knowledge is needed if the increased capability of equipment is to be used effectively.

Fennoscandia recognizes the interrelatedness of all phases of reforestation. The Metsäteho (Work Study Section of the Central Association of Finnish Forest Industries) stepwise model for evaluating the cost of activities in the regeneration chain includes biological as well as economic input. The success of reforestation can be influenced by choice of species, stock quality, site preparation, planting, cleaning, and plantation maintenance.

Active technology exchange between Canada and Fennoscandia can provide British Columbia with an opportunity to gain experience in site-specific mechanized silviculture, without incurring all the costs of gaining that experience. Doubtless, Swedish and Finnish manufacturers and foresters will also continue their interest in British Columbia forests and silvicultural practice as an information bank of related experience, as a source of genetic material, and as a potential market for equipment.

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PERSONAL COMMUNICATIONS

Appelroth, S.-E., Finnish Forest Research Institute

Bedford, L., Silviculture Branch, British Columbia Ministry of Forests and Lands, Canada

Berg, S., Skogsarbeten, Spånga, Sweden

Haataja, P., TTS, Rajamäki, Finland

Kukkonen, E., Hakmet Ltd., Montreal, Que., Canada

Tolonen, M. Teräskomponentti Ky, Heinola, Finland

APPENDIX 1. Directory of Swedish and Finnish mechanical site preparation equipment

Implement/Type	Manufacturer	Canadian Representative
Bräcke Scarifier/Mounder	Robur Maskin AB Box 150 840 60 Bräcke Sweden 0693-10575	KM Forestry Consultants Inc. 360 Mooney St. Thunder Bay, Ont. (807) 344-0811
Donaren 180D/280 Disc Trencher	AB Skogsmaskiner Box 5 783 00 Säter Sweden 0225-51080	Canadian Forestry Equipment Edmonton, Alta. (403) 484-6687 Mississauga, Ont. (416) 678-1586 Montreal, Que. (800) 361-5572 Dartmouth, N.S. (902) 465-2558
Fiab MB Disc Trencher	Forest Innovation AB 920 53 Stensele Sweden 0951-20360	
HMF Scarifier/Mounder	Teräskomponentti KY Statmatia 1 181 00 Heinola Finland 910-56190	Canadian Forestry Equipment
Leno Scarifier	Olofsfors AB 910 00 Nordmaling Sweden 0930-10700	Canadian Forestry Equipment
Marttiini Plow	Marttiini KY Box 23 961 01 Rovaniemi Finland 960-15211	Marcan Equipment Ltd. 241 Cedar Ave. Thunder Bay, Ont. (807) 767-4367 (807) 345-0231
MM Disc Trencher	Veljekset Mikkonen 799 70 Poikiinaho Finland 972-66124	Canadian Forestry Equipment
Murveln Disc Trencher	Järvsö Hytten AB Skärstra 4047 820 40 Järvsö Sweden 0651-32250	Canadian Forestry Equipment

APPENDIX 1. (cont'd)

Implement/Type	Manufacturer	Canadian Representative
Sinkkilä Mounder	Tuuvesi KY 16630 Tennilä Finland 918-85508	Canadian Forestry Equipment
TTS Delta Disc	Työtehseura RY Metsäkolasema 052 00 Rajamäki Finland 90-2901033	Hakmet Ltd. 881 Boul. Harwood Dorion, Que. (514) 445-6101
	Työväline OY Karapellontie 12 026 10 Espoo Finland 90-594411	312 - 1717 3rd Ave. Prince George, B.C. (604) 562-2759
Wadell Cone Trencher	Wadell Patent AB Skeppsgården 615 00 Valdermarsvik Sweden 0493-41160	Dick Johnsson Swedish Trade Council 115 Dorchester Blvd. Montreal, Que. (514) 878-4461
	Storebro Bruks AB 590 83 Storebro Sweden 0492-30160	

APPENDIX 2. Technical data for mechanical site preparation equipment[a]

	Bräcke Mounder	Donaren 180D/280	HMF Scarifier
Minimum power requirement of prime mover	80-100 kW	90-115 kW	90-115 kW
Required hydraulic pressure/flow	separate motor on implement	170 bar 85 L/min	internal hydraulic implement, lifting of arms by prime mover
Maintenance	diesel motor checked and lubricated daily	12 daily lubrication points, bolt tightening and check oil levels of speed reduction gears	16 daily, 4 self-lubricating points, regular bolt tightening
Wearing parts	ripper teeth mounding scoop	10 replaceable teeth/disc	ripper teeth
Weight	4000 kg	2300 basic 2800 driven	3000 kg
Cost in Canada (1987)	$75 000	$59 500	$63 000
No. in Canada (1987)	6	7	1

APPENDIX 2. (cont'd)

	Marttiini AKLM 190 Plow	TTS Delta	Wadell Cone Trencher
Minimum power requirement of prime mover	103 kW	110 kW	80 kW with hydrostatic transmission commonly 70 kW with auxiliary motor
Required hydraulic pressure/flow	70-200 bars 60-150 L/min	max 170 bar basic 80 L/min driven 130 L/min	170 bar 180 L/min
Maintenance	9 daily, 1 biannual lubrication points	14 daily lubrication points, regular bolt tightening and checking oil levels of speed reduction gears	14 daily lubrication points
Wearing parts	cutting blades and noses		32 replaceable teeth/cone, cone washers
Weight	4500 kg	2600 basic 3000 driven	2000 kg
Cost in Canada (1987)	$85 600	$59 000	$80 000
No. in Canada (1987)	0	27	1

* From Hallonborg (1986), manufacturers and Canadian distributors.

APPENDIX 3. Site preparation machinery evaluation studies

Some Fennoscandian studies evaluating the effectiveness of the machines described in the report are summarized in this appendix.

Frequent references are made to Skogsarbeten's terrain classification scheme for forestry. The most familiar recent reference for the scheme is Nilsson and Berg (1979). English descriptions of the terrain classification system are available in Skogsarbeten (1969), Eriksson *et al.* (1978) and Stjernberg (1985).

APPENDIX 3.1 BRÄCKE MOUNDER

Adelsköld (1986)

A Bräcke Mounder and an HMF Scarifier were tested on three sites with increasing degrees of terrain difficulty (Table 3.1.1). The easy site had a stone-free, sandy soil. The medium site had a normal stony, morainal soil, and the difficult site had a bouldery, morainal soil. Slash, which averaged 15 cm in depth, covered 20-40% of the area of all sites.

The Bräcke Mounder averaged 2400 planting spot attempts per hectare compared to 1900 for the HMF Scarifier. The percentage of attempts that were plantable mounds decreased with increasing terrain difficulty (Figure 3.1.1). On average, the Bräcke Mounder created 500-700 more mounds per hectare than the HMF Scarifier, although the HMF Scarifier mounds were generally taller, at 15 cm, than the 10 cm average for the Bräcke Mounder. Boulders and stumps were the chief obstacles obstructing mound formation by the Bräcke Mounder. Rate of travel had little effect on mounding success.

TABLE 3.1.1. Terrain description[a] of machine test sites

	Relative Degree of Terrain Difficulty		
	Easy	Medium	Difficult
Soil type	medium sand	sandy moraine	sandy-silty moraine
Soil depth	deep	deep	shallow
Surface structure class	1	1	2-3
Slope class	1	1	2
Stone ratio class	1	3-4	5
Stone ratio (%)	0	30-50	60-80
Slash and stumps class	2-3	3	3

a Skogsarbeten Terrain Classification (Nilsson and Berg 1979). Adapted from Adelsköld (1986)

When the area of exposed mineral soil was added to the area of mounds in planting spot attempts, the planting spots formed by the HMF Scarifier were larger than those formed by the Bräcke Mounder (Table 3.1.2). Although the number of planting spots declined with increasing terrain difficulty, when exposed mineral soil is included, both machines met the minimum requirement (more than 70% of the 2500 spots per hectare should be plantable) for number and size of planting spots on difficult terrain.

Adelsköld and Hallonborg (1986a)

A study in northern Sweden showed that a Marttiini Plow prepared considerably more elevated planting spots than either the Bräcke Mounder or the HMF Scarifier. More details of this report are given in Appendix 3.2.

TABLE 3.1.2. Length and area of exposed mineral soil for planting spot, and percentages of exposed mineral soil and disturbed area for test site, with 2-m spacing between rows[a]

	Bräcke			HMF Scarifier		
Relative degree of difficulty	E	M	D	E	M	D
Number of plots (20 x 5 m)	4	10	9	2	10	9
Rate of travel km/hr	2.70	3.06	3.06	2.46	2.94	2.52
Per-plot length of mineral soil (dm)	11	11	8	10	9	7
Area of mineral soil (dm^2)	50	50	30	70	60	40
Exposed mineral soil for test area (%)	12	11	6	16	15	7
Disturbed area (%)	25	25	20	30	30	25

[a] Adapted from Adelsköld (1986)
E Easy terrain difficulty.
M Moderate terrain difficulty.
D Difficult terrain.

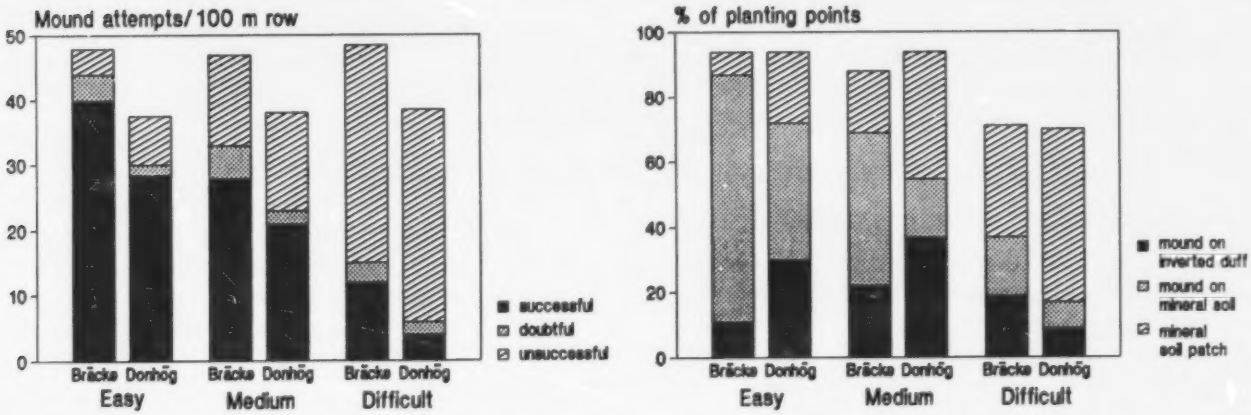

FIGURE 3.1.1. Number of successful, questionable, and unsuccessful mound attempts per 100 m for the Bräcke Mounder and HMF Scarifier (Donhög) on three types of terrain and distribution of planting positions. Adapted from Adelsköld (1986). Used with permission of Skogsarbeten.

APPENDIX 3.2 HMF SCARIFIER

Adelsköld (1986)

In a study comparing the HMF Scarifier with the Bräcke Mounder, the HMF Scarifier was found to form larger but fewer mounds than the Bräcke Mounder (Appendix 3.1). Since the controls of the HMF Scarifier were set for 2-m spacing between mounds, the size of mounds was smaller than the maximum possible. The average height of mounds was 15 cm at 2.6-m spacing. A maximum of 1500 of the 1900 mound attempts per hectare were judged plantable. Terrain difficulty was a significant determinant of mound quality. On easy terrain, 80% of mound attempts were successful compared with 15% on difficult terrain. In each terrain difficulty class the Bräcke Mounder had somewhat more successful mound attempts than the HMF Scarifier (Figure 3.1.1). Slash, stumps, stones, and soil depth also affected mound quality.

Adelsköld and Hallonborg (1986a)

The HMF and Bräcke Mounders were compared with disc trenchers and the Marttiini Plow on three sites in northern Sweden. At the Jokkmokk site, obstacles to site preparation were frequent and the soil was wet, fine-textured and resistant to treatment. The HMF Scarifier exposed nearly twice as much mineral soil as the Bräcke Mounder, although mound attempts were fewer; 1350 per hectare for the HMF Scarifier compared to 1650 for the Bräcke Mounder. Successful mounds were formed on 85% of the HMF Scarifier mound attempts, compared to 70% for the Bräcke Mounder, each giving similar numbers of successful mounds (ca. 1150 per hectare). The high frequency of stones both on and under the surface at the Lycksele site reduced mound success to 55% of the 1900 mound attempts per hectare made by the HMF Scarifier. The stoniness of the Älvdalen site likewise hindered successful mound formation by the mounders. The number of elevated planting spots formed by a Murveln disc trencher (1300 per hectare) was similar to the numbers formed by the mounders (HMF and Bräcke).

Hämäläinen (1987)

Metsäteho (the Finnish Department of Operations Efficiency) studied two HMF Scarifiers for 1500 working hours over 450 ha during the 1985 field season. The distance between mounds was set for 2 m. Dry sites were patch scarified and wet sites were mounded. The average productivity for the two machines per G15[a] hour was 0.7 and 0.3 ha/hr. The ripper teeth on the second machine were set at a steep angle which increased resistance and decreased productivity. The number of mounds decreased when stony soil was prepared. Mineral soil exposure provided adequate numbers of planting spots on stony ground, although the number of inverted humus mounds decreased on the stony sites. Hämäläinen (1987) suggests that further work studies are required to determine how well site preparation machines perform under different biophysical conditions, such as fine soil texture and dense competing vegetation.

APPENDIX 3.3 MARTTIINI AKLM 190 PLOW

Adelsköld and Hallonborg (1986a)

Results from a trial comparing various site preparation implements (Figure 3.3.1) showed that the Marttiini AKLM 190 Plow provided the greatest number of elevated planting spots: 2200 per hectare out of a possible 2500 per hectare.

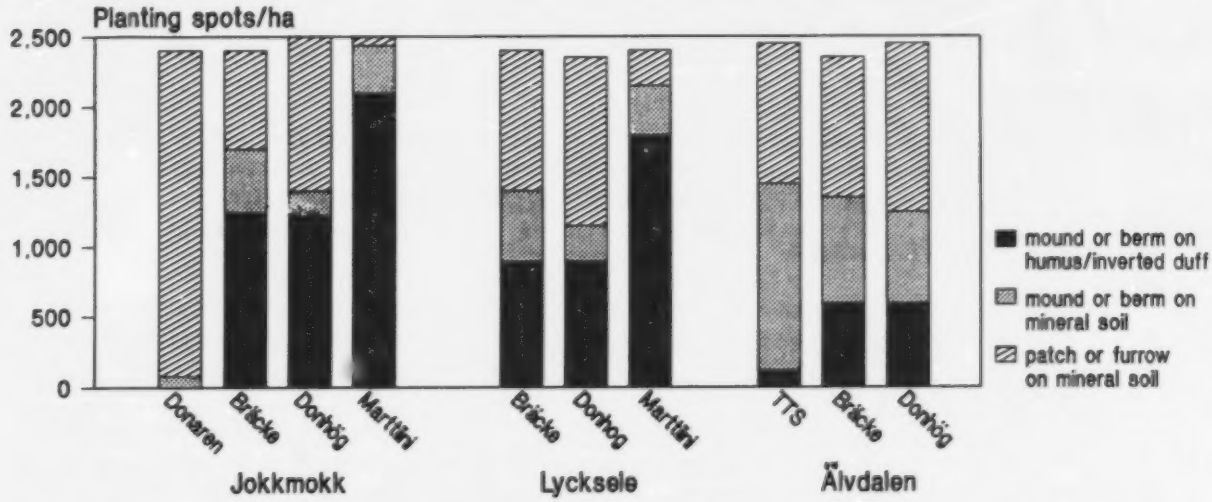

FIGURE 3.3.1. Planting position quality for three sites in northern Sweden. Adapted from Adelsköld and Hallonborg (1986). Used with permission of Skogsarbeten.

[a] A G15 hour means that the smallest measuring unit is 15 minutes.

Manufacturer's Brochure

The five basic plowing profiles illustrated in the manufacturer's brochure (Figure 3.3.2) are as follows:

1. Normal plowing for poorly drained sites and sites with thick, raw humus.
2. Shallow plowing for sites with cold soils, medium thickness of raw humus, fine soil texture, fine loamy sand with limited percolation rates, and soils that would benefit from improved drainage.
3. Surface plowing for well drained sites on which furrows are recommended to encourage natural regeneration, to protect steep slopes, and to avoid stony soils. Three degrees of surface plowing are recommended:
   - removal of surface layers to expose a wide strip of mineral soil;
   - removal of the surface organic matter and some surface soil for the full plow width, using the extendable plow wing screefers; and
   - "heel" plowing to remove the surface organic matter, using the extendable plow wing screefers; recommended for upland sites with a thin humus layer.

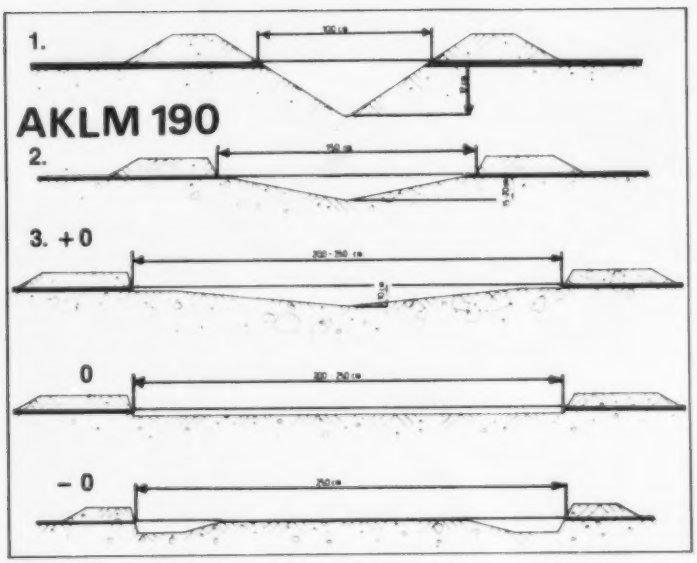

FIGURE 3.3.2. Some possible profiles of the Marttiini AKLM 190 Plow. Adapted from manufacturer's brochure.

APPENDIX 3.4 DONAREN 180D AND 280 DISC TRENCHERS

Adelsköld and Uggla (1986)

The Donaren 280 Disc Trencher was investigated on dry, moist, and wet sites (Table 3.4.1) to determine whether site-specific treatments could be made with a limited number of settings. Intermittent and continuous cultivation (patches or furrows) were used with two downpressures and three nominal disc rotation speeds (Table 3.4.2).

TABLE 3.4.1. Terrain description[a] of machine test sites

Site Type	Soil/Vegetation Type	Slope Class	Cultivation Resistance Class	Stone Ratio Class
Dry	sandy moraine/ cranberry	1	3	4-5
Sub-mesic	sandy-silty moraine/small leaf grass	2-3	3	3-4
Wet	silty moraine/ sedge horsetail	1	4	3

[a] Skogsarbeten Terrain Classification (Nilsson and Berg 1979). Adapted from Adelsköld and Uggla (1986).

On the dry site, normal disc rotation speed (25 rpm) and no downpressure were used because limited soil exposure is recommended on dry sites to minimize nutrient leaching and water loss. Discontinuous cultivation is considered adequate unless the frequency of obstacles would reduce the number of plantable spots below an acceptable number.

On the fresh (moist) site, low downpressure but higher disc rotation speed (40 rpm) than on the dry site were tested because increased mineral soil exposure may be needed for adequate soil warming. Mounds or berms above the general soil level are recommended on fresh sites because drainage around seedling rooting is improved in such elevated planting spots. Two different lengths of patches (interrupted furrows) were compared with continuous furrows to determine whether the recommended level of mineral soil exposure was achieved. Interrupted furrows do not drain the whole site, and minimize erosion on slopes.

TABLE 3.4.2. Settings used on Donaren 280[a]

Site Type	Cultivation Alternative	Ground Pressure (kN)	Rotation Speed (rpm)	Interval (m) Up	Interval (m) Down
Dry	intermittent			1	1
	continuous	7	25	-	-
Fresh	intermittent	7	40	1	1
	intermittent	7	40	1	5
	continuous	7	30/40	-	-
Wet	continuous	13	30/40	-	-

[a] Adapted from Adelsköld and Uggla (1986).

On the wet site, increased downpressure, high nominal rotation speed (30-40 rpm), and continuous cultivation were tested because improved site drainage and sufficient mineral soil exposure for release nutrients and soil warming are recommended.

On the dry site, the average area per patch was 70 dm². Mineral soil equal to or above the surrounding ground level occurred in 70% of the patches (Figure 3.4.1). Exposed mineral soil occurred on 75% of the length of the continuous furrow. Mineral soil equal to or above the ground surface occurred on 40% of the furrow length. The total disturbed area was about 40% for patches and 60% for furrows. This difference increased with more difficult terrain.

On the fresh site, 90% of the short patches were successful and their average size was 80 dm². Mineral soil equal to or above ground level occurred in 70% of the patches. Amount of total area disturbed was 40% for short patches, 45% for long patches, and 65% for continuous furrows. Amount of treated area that consisted of exposed mineral soil was 70% for the long patches and 80% for the furrows. The percentage of plantable spots that were elevated above ground level was 70% for the long patches and 90% for the furrows.

On the wet site, 80% of the furrow length had mineral soil exposed, but it quickly filled with water. However, 60% of the exposed mineral soil was at or above ground level. Much of it covered inverted duff. The total area of disturbance was 70%. Increased disc rotation speed here, compared with that on the other sites had no discernible effect.

Intermittent cultivation with long patches provided as many plantable spots as continuous furrows, but without as much mineral soil exposure. Limiting the amount of mineral soil exposure may be advantageous on areas where competing vegetation can seed or sprout.

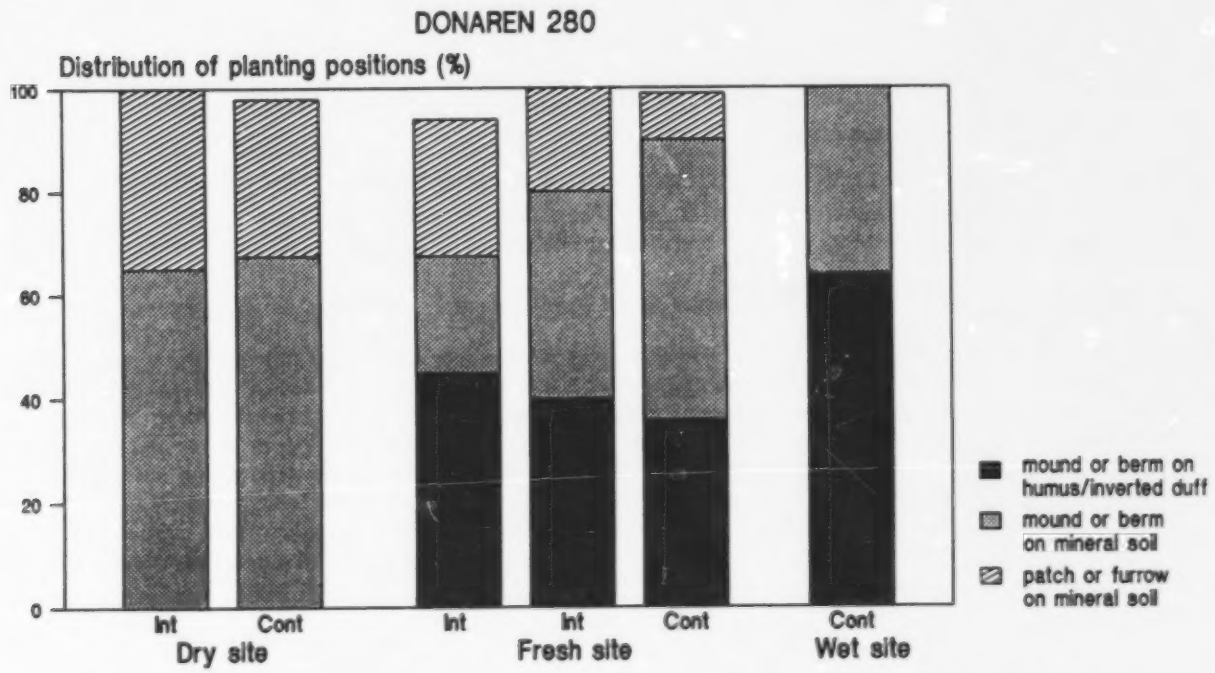

FIGURE 3.4.1. Planting position quality by site for intermittent (Int) and continuous (Cont) cultivation. Adapted from Adelsköld and Uggla (1986). Used with permission of Skogsarbeten.

This trial showed that differences in amount of mineral soil exposure were obtained on different sites with different settings of the Donaren 280. It also indicated that discontinuous operation prepared an adequate number of plantable spots in the dry and moist sites. Continuous operation would not be necessary with the amount of impediments to site preparation present on these sites. The value of the Donaren 280 having discontinuous as well as continuous operation was therefore demonstrated.

APPENDIX 3.5 TTS DELTA DISC TRENCHER

Appelroth (1986)

A comprehensive work study in Finland on the effects of different adjustments on work quality (furrow width and depth[1]) used three downpressures, two disc rotation speeds, three disc angles, and three rates of travel. Sites varied over three stoniness, humus thickness, and slope classes. Slash loads were light.

Increased downpressure increased width of exposed mineral soil up to 20 cm at the low travel rate, but only by 10 cm at the high rate. Otherwise, rate of travel had little effect on work quality. Mean width of exposed mineral soil was 26.5 cm and mean furrow width was 45.9 cm averaged for the three rates of travel. Increased speed of disc rotation increased the width of exposed mineral soil slightly (5-10 cm). Powered rotation of the discs mostly provides improved slash penetration.

Since travel rate has been found to have little effect on work quality, travel rate would seem to be a function of operator motivation and comfort. The Canadian TTS dealer claims that, under easy conditions, productivity of 2 ha/hr is possible at the high travel rates customary in Canada. Under demanding conditions (slopes up to 40% with slash and boulders), production may drop to 0.6-0.7 ha/hr (E. Kukkonen, pers. comm., Hakmet Ltd., Montreal, Que.). Differences in productivity are also likely to be affected by the required number of plantable spots per hectare, which is generally higher in Fennoscandia (2500 per hectare) than in British Columbia (1200 per hectare).

APPENDIX 3.6 WADELL CONE TRENCHER

Gustafsson and Morenius (1980)

Results from a study using an early model of a Wadell Cone Trencher on a fresh site (covered in sandy to silty morainal soil with a high frequency of stones) showed that most planting spots were below ground level. Average width of disturbed strip was 50 cm, with 50 cm of exposed mineral soil. Furrow depth averaged slightly less than 10 cm.

Gyldberg (1986)

A work study on two sites in Central Sweden using two rotation speeds and three downpressure settings (4, 10, and 14 kN)[2] showed that length and width of exposed mineral soil were statistically different with different settings. Increased downpressure and disc rotation speed increased mineral soil exposure, area of disturbance, distance of planting spot (if centrally located) to nearest humus, depth of planting spot below ground level, and soil porosity of the planting spot. The influence of disc rotation speed decreased with increasing downpressure. At 13 kN, essentially the same results were obtained with both rotation speeds. No statistically valid differences were found between terrain factors and site preparation results, perhaps because the two sites were relatively similar, with high within-site variation. Gyldberg, nevertheless, concluded that site treatments could be changed by varying disc rotation speed and downpressure.

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[1] It is of interest to note that work quality was equated with amount of mineral soil exposure. Separate measurements of mineral-covered inverted humus were not made since differentiation of such planting spots was not considered to represent a difference in the quality of the planting spot. Until recently, most emphasis in Fennoscandia has been on mineral soil exposure as the primary factor governing plantability of the prepared spot. Elevation in relation to ground level and the opportunity of seedlings to reach the nutrients in the humus layer quickly had received little attention.

[2] The downpressure settings that could be used are as follows:

reduced weight III	1.0 kN/cone
reduced weight II	4.0 kN/cone
reduced weight I	7.0 kN/cone
own weight	10.0 kN/cone
increased weight III	11.5 kN/cone
increased weight II	13.0 kN/cone
increased weight I	18.0 kN/cone

Adelsköld and Hallonborg (1986b)

A multi-phase Wadell Cone Trencher was studied on three contrasting sites (Table 3.6.1) in 1986 to determine if a limited number of alternative settings (Table 3.6.2) could produce site-specific treatments. On the dry site, where only limited disturbance of the humus is recommended, the cones were set at a slight angle and downpressure was low. A high disc rotation speed was used for intermittent operation so that the cone teeth could penetrate the humus layer quickly.

On the fresh site, the cones were tilted for aggressive cultivation, with the intent of shaping elevated planting spots. Either intermittent or continuous cultivation can be appropriate on fresh sites, depending on the frequency of obstacles to treatment and the need to reduce erosion potential. On the wet site, high disc rotation speed and downpressure were used to increase the chance of penetrating the humus and creating elevated planting spots.

TABLE 3.6.1. Description of machine test site[a]

Site Type	Soil/ Vegetation Type	Stone Ratio Class	Cultivation Resistance Class	Slash/ Stump Class	Slope %
Dry	silty moraine/ cranberry	3-5	2	2	20
Sub-mesic	clay moraine/ grass	2-3	3	2	20
Wet	clay moraine/ grass	3	4	2	20

[a] Skogsarbeten Terrain Classification (Nilsson and Berg 1979). Adapted from Adelsköld and Hallongborg (1986b).

On the dry site, 80% of the patch attempts were successful, with elevated planting spots present in 75% of the patches (Table 3.6.3). The disturbed area was 20% for patches and 40% for furrows. Elevated mineral soil planting spots occurred along only 15% of the furrow length.

TABLE 3.6.2. Settings used on the Wadell Cone Trencher test[a]

Site Type	Cultivation Alternative	Cone Angle (degrees)	Rotation Speed (rpm)	Downward Pressure (kn)
Dry	intermittent			7
	continuous	7	24	7
Fresh	intermittent	18	24/32	12
	continuous	18	24/32	12
Wet	continuous	18	38	12

a Adapted from Adelsköld and Hallonborg (1986b).

On the fresh site, 85% of the patch attempts were successful, with elevated planting spots present in 70% of the patches because mineral soil collected on one side of the patch. No difference in patch configuration was detected between rotation speeds. Disturbed area with continuous cultivation was similar (50-51%) for both disc speeds. However, furrow width was greater for higher speed, as was the proportion of elevated planting spots (74-36%).

TABLE 3.6.3. Work quality of Wadell Cone Trencher on three sites with various settings[a]

Type	Cultivation Alternative	Nominal Rotation (rpm)	Exposed Mineral Soil		Mineral Soil Equal to or Above Ground Surface		Area Disturbance (%)
			Patch area dm^2	Furrow width cm	Patch % of no.	Furrow % of length	
Dry	intermittent	32	43	-	75	-	20
	continuous	24	-	30	-	15	45
Fresh	intermittent	24	51	-	67	-	36
		32	50	-	71	-	30
	continuous	24	-	48	-	36	50
		32	-	80	-	74	50
Wet	continuous	38	-	79	-	74	60

[a] Adapted from Adelsköld and Hallonborg (1986b).

On the wet site, area of disturbance with the settings used was somewhat higher than on the fresh site, but position of planting spots and width of furrows were similar to those formed by continuous cultivation in fresh sites.

The results indicated that different combinations of cone angle, disc rotation speed, and downpressure can give site-specific treatments. The Wadell Cone Trencher, however, seems to have limited capacity for producing planting spots consisting of mineral soil above inverted humus, which is recommended for wet, fine-textured soils in northern Sweden. Recommended patch size of 35 dm^2 was not attained on one-third of the patches formed on the dry site and on one-quarter of the patches on the fresh site.

Rotation speed was shown to be important in determining the area and elevation of planting spots. Adelsköld and Hallonborg believed that compaction of the rotovated materials is important. This observation, however, may not have taken into account the settling that occurs over winter.

Productivity of the Wadell Cone Trencher during tests in Quebec was 0.7 ha/hr during the first 50 hours. An increase to 0.9 ha/hr is expected with continued operation (Tellier 1986). In Sweden, productivity averages 0.7 ha/hr. G. Wadell, the developer of the trencher, considers that higher rates could only be achieved by sacrificing quality of site preparation and may damage the machine. He recommends that travel speed not exceed 2.4-2.7 km/hr (40-45 m/min).